Conspicuous leisure, time allocation, and obesity Kuznets curves

Nathalie Mathieu-Bolh*and Ronald Wendner†

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Abstract

Our theoretical growth model studies the complex patterns of income and obesity, accounting for changes in behavior related to exercise. By combining Becker's (1965) theory of time allocation with Veblen's (1899) theory of conspicuous leisure, our model determines conditions for a static and a dynamic Kuznets curve for obesity. Both curves result from the interaction between the rising opportunity cost of exercise and peer effects. Both effects rise with income, whether we consider income cross-sections, or economic development over time. Focusing on calorie expenditure, we shed light on mechanisms explaining the rise and slowdown in obesity prevalence in the USA, and the correlation between obesity and income per worker (positive in developing countries and negative in industrialized countries). Our numerical simulations indicate that exercise choices have slowed down the rise in obesity prevalence, but do not generate a dynamic Kuznets curve in the USA. Peer effects would need to be larger than empirically observed for a dynamic Kuznets curve to occur. By contrast, we find a static Kuznets curve, which peak corresponds to a per worker capital stock 25% higher than its current average level, and an average weight of 187 pounds. We discuss policy implications of our findings.

Keywords: Obesity, Status, Conspicuous leisure, Inequality, Kuznets Curve, Economic Development.

JEL classification: D11, D30, H31, I15, O41.

1 Introduction

The Covid-19 pandemic has been accompanied by an increase in average body weight, which is a stern reminder that obesity remains a major public policy issue involving significant private and social costs. The literature review by Mathieu-Bolh (2021b) shows that the link between income and obesity seems to follow a Kuznets curve pattern. To explain this pattern, the theoretical literature has essentially focused on food consumption choices, assuming exogenous preferences. However, the decrease in physical activity during confinement underlines that calorie expenditure is important to maintain healthy body weights (e.g. Ziegler et al. 2020),[1] and it is likely that preferences are not fixed but change over time (Bowles, 1998). Therefore, focusing on exercise choices and changing preferences, we build the first theoretical growth model that combines Becker's (1965) theory of the allocation of time and Veblen's (1899) theory of conspicuous

*University of Vermont, Department of Economics, Old Mill 94 University Place, Burlington VT 05405, U.S.A. Email nmathieu@uvm.edu. Tel: 1 (802) 656 0946.

†Department of Economics, University of Graz, Austria Universitaetsstrasse 15, RESOWI-F4, A-8010 Graz, Austria. E-mail ronald.wendner@uni–graz.at; Tel +43 316 380 3458.

[1] The decrease in physical activity relates to gym closures as well as to the lack of normal daily routine that usually provides structured exercise and spontaneous physical activity (Bhutani and Cooper, 2020), and correlates to the increase in the use of television and internet connected devices and applications (Nielsen report, 2020).

leisure to explain complex obesity income patterns. We simulate our model to describe obesity patterns in the US. We discuss the fact that our model also provides a tool for policy analysis.

So far, most theoretical explanations of the link between income and obesity focus on the role of food consumption. Some contributions explain the historical rise in obesity (Dragone, 2009; Dragone and Ziebarth, 2017; Burke and Heiland, 2007; Levy, 2002 and 2009; Dragone and Savorelli, 2012; Strulik, 2014; Mathieu-Bolh, 2019 and 2021a). Other contributions explain the inverse relation between income and obesity for population cross-sections in rich countries (Cutler et al., 2015; Fuchs, 1982; Grossman, 1972; Cawley and Ruhm, 2012; and Mathieu-Bolh, 2021a). Two articles provide insights on the changing link between income and obesity focusing on food consumption. For Phillipson and Posner (1999), as economies develop, the change in the relation between income and obesity, from positive to negative, relates to the assumption that rich individuals exogenously care more about their health and weight than poor individuals, and to complementarity between consumption and weight. Mathieu-Bolh and Wendner (2020) is the only article that includes endogenous preferences with respect to food consumption. As economies develop, the dominating income effect makes individuals increase calorie consumption. After a certain income threshold, the dominating dynamic status effect makes individuals prefer low-calorie food over high-calorie food and decrease their calorie intake. In addition, only a few theoretical contributions explore the role of calorie expenditure in models with exogenous preferences. The static model by Yaniv et al. (2009) analyzes optimal choices made by weight conscious and weight unconscious consumers accounting for interactions between food consumption choices and physical activity. Dynamic models by Lakdawalla et al. (2005) and Lakdawalla et al. (2009) argue that in rich countries, people are heavier than in poor countries because technological progress leads to more sedentary work and raises the cost of physical activity. In rich countries, where work-place technology is more uniform, rich people are thinner than poor people because the authors assume that the demand for thinness is exogenously higher among rich individuals. Therefore, there is to this date no dynamic model with endogenous preferences that incorporates exercise choices to explain the changing link between income and obesity.

Our model directly extends the theoretical literature by combining Becker's (1965) theory of the allocation of time and Veblen's (1899) theory of conspicuous leisure in a growth model. We extend Becker's (1965) theory (followed by Gossen, 1983, LeVan et al., 2018, Ha-Hui et al., 2019) in two ways. In the first place, we acknowledge that there are two types of consumption goods, those that do not require time and those that do, and we introduce a distinction between sedentary leisure and exercise. We associate time consuming expenditure to exercise. For example, the purchase of a gym pass is associated to spending time exercising. Exercise choices therefore involve a double cost, the exogenous price paid for consumer goods (such as the cost of a gym pass) and the endogenous opportunity cost of exercise. This assumption reinforces the rising opportunity cost that goes with capital accumulation and pushes individuals to exercise less. This mechanism is important for two reasons. First, it can explain the decrease in exercise and calorie expenditure and the rise in obesity. Second, it has implications for policy analysis as exercise choices can be influenced through two channels, consumer prices and wages.

However, accounting for the rising opportunity cost of exercise alone would yield counterfactual results with respect to two empirical facts: in population cross-sections, high income earners tend to exercise more and weight less than low income earners; obesity prevalence declines beyond a certain income threshold as captured by the empirical obesity Kuznets curve (e.g. Clément, 2016). Thus, in the second place, we introduce comparison utility in our model, which reflects the fact that individuals' exercise choices are influenced by their peers. The genealogy of this idea is Veblen's (1899) theory of conspicuous leisure, which we incorporate in the growth model. According to Veblen, conspicuous leisure is visible leisure in which people engage with the objective of displaying and reaching a certain status. We apply the idea of visible leisure to time consuming exercise expenditure. Consistent with the literature on peer effects, in order to capture such comparisons, we introduce a reference level for exercise. The taste for exercise relates to the extent to which people compare themselves to the reference, described as the degree (strength) of peer influence. The implication of such a reference level is that the own marginal utility of exercising increases with the reference level, which is endogenously determined in our model. In other contexts, this type of mathematical formulation is referred to as positionality. Specifically, we extend the literature on endogenous positionality (e.g. Dioikitopoulos et al. 2019 and 2020; Akay and Martinsson, 2019; Mathieu-Bolh and Wendner 2020), which establishes that the degree of peer influence changes over time due to changes in economic development or inequality. In accordance with this literature, in our model, the degree of peer influence has two components. An exogenous component reflects individual rank in society and an endogenous component is tied to capital accumulation. While exogenous differences in taste exist at all times, as the stock of capital accumulates, everyone's taste for exercise increases. As a result, ceteris paribus, individuals exercise more as the stock of capital increases. We refer to this change in the degree of peer influence as the dynamic peer effect. Additionally, consistent with the past literature on endogenous preferences (Mathieu-Bolh and Wendner, 2020), in our core framework, individuals are assumed to be weight conscious but they are not calorie conscious. In other words, excess weight rather than weight gain causes disutility. This implies that individuals do not count calorie when they make consumption or exercise decision, which is key to maintain mathematical tractability. However, we also provide a brief extension and the main intuitions for the model with calorie conscious individuals.

The rising opportunity cost and the dynamic peer effect create a wedge between optimal exercise and food consumption choices of individuals with different socioeconomic status as economies develop. As a result, our model explains the changing link between income and obesity as a reflection of dynamic peer effects competing with the rising opportunity cost of exercise.

Empirical facts support that individuals have become increasingly influenced by peers with respect to exercise choices. While the empirical literature on leisure initially did not find evidence of positionality with respect to overall leisure time (Carlsson, Johansson-Stenman, and Martinsson, 2007), recent findings suggest that there has been a change in positional behavior from goods purchased to how time is spent (Holthoff and Scheiben, 2018). Furthermore, individuals are highly positional with respect to physical attractiveness (Solnick & Hemenway, 1998). Individuals work-out to be thin, which in empirical studies is linked to attractiveness, especially for women (Fletcher et al., 2014). Additionally, the psychology literature shows that peers influence exercise behavior in adolescents (Jihey Chung et al., 2017), and adults (Ingledew et al., 1998). Thus, it makes sense to assume that exercise choices are influenced by peer behavior in the same way as some healthy food choices are. The assumption that peer influence has increased is further supported by the increase in the portion of the population using social media, as well as the rise in the number of followers of sport and fitness influencers.[2] Additionally, social fitness applications (such as Fitbit, Garmin Connect, Nike Run Club, PumpUp, Stava, etc) that track individuals exercise activities and compare them to their family, friends, or larger group of users have increasingly become popular in the USA.[3]

[2]For example, the number of Instagram users has increased from 100 million in 2010 to 800 million in 2017. The number of followers of the top 20 fitness influencers on Instagram reached almost 100 million individuals in 2017 (Influencer Marketing Hub, 2021).

[3]The number of health and fitness application users has increased from 62.7 million users in 2018 to 87.4 million in 2020 (Statista, 2021).

Furthermore, exercise choices differ according to income. First, individual's calorie expenditure through labor is tied to economic development (Church et al., 2011; Shuval et al., 2017). While Lakdawalla et al. (2005) and Lakdawalla et al. (2009) have focused on calorie expenditure related to technological progress and work, we are focusing on calorie expenditure related to leisure time. The 2008 BLS Spotlight on Statistics covering time spent on sports and exercise, provides insights on differences in the practice of exercise between different income groups (see Figure A1 in the appendix). It shows that 10 percent of people with less than a high-school diploma engage in those activities, while 23 percent of individuals with a bachelor's degree or higher engage in those activities.[4]

If exercise choices were solely the mirror of calories spent at work, there would be no difference between overall calorie expenditure of individuals with low-income strenuous jobs and high-income sedentary jobs. Thus, exercise choices may also be the result of other factors, such as peer effects. Indeed, peer effects seem to be concentrated on high income earners as highlighted by Western et al. (2021), who find that digital technologies targeting physical activities are not effective on individuals with low socioeconomic status but make individuals with high economic status more active.

Our main theoretical results are as follows. We show the existence of both a dynamic and a static Kuznets curve for obesity. Recall that in the empirical literature, the Kuznets curve is initially presented as a dynamic relation between economic development and obesity. However, empirical studies solely demonstrate the existence of a static Kuznets curve for population cross-sections (Clément, 2017; Grecu and Rotthoff, 2015) or cross-country analysis (Windarti et al., 2019; Deuchert et al.'s, 2014). To show the change in the relation between income and obesity over time, Clément (2017), resorts to two separate cross-sectional analyses covering two different time periods in China. By contrast, our theoretical model generates both a dynamic and a static obesity Kuznets curve, which complements the empirical literature on this topic, and is a new concept in the theoretical literature. Our results differ from Mathieu-Bolh and Wendner (2020) who do not describe the two Kuznets curves and ignore the role of exercise in describing obesity patterns.

We provide a novel explanation for the dynamic and static Kuznets curves. First, the difference between the growth rates of consumption and exercise reflects two competing effects with economic development: both the opportunity cost of exercise and peer influence for exercise increases. The former (latter) renders the difference between the growth rate of food consumption and exercise larger (lower) over time.[5] Second, we formally demonstrate that there is a level of capital per worker for which the growth rate of exercise starts exceeding the growth rate of food consumption. Therefore, in a steady state, both the opportunity cost of exercise and peer influence increase with the steady-state stock of capital, up to a certain threshold beyond which the correlation between steady-state body weight and the stock of capital per worker is negative. This explains the negative correlation between body weight and income for high income levels per worker in cross-sectional analyses of individuals or countries with different incomes per worker.

Furthermore, we show that in the presence of dynamic peer effects, for high levels of economic development, body weight gain becomes negative as the economy develops over time. The static analysis provides an additional result: For high levels of steady-state stock of capital per worker, the link between body weight and steady state capital stock is negative only for high degrees of peer influence. Last, we show that accounting for calorie consciousness reinforces the choice of exercise over consumption and is likely to result in

[4]see the Appendix for discussion on empirical evidence about exercise choices and income.

[5] In our model, economic development is captured by the stock of capital per worker (identical to the per capita stock of capital) which, given technology, fully determines income per worker.

lower equilibrium body weight. However, accounting for calorie consciousness does not alter the fundamental driving forces of obesity tied to peer effects and opportunity costs.

We supplement the qualitative analysis with a quantitative analysis relying on numerical simulations. We use a standard calibration procedure, which consists in matching the model's steady state equilibrium characteristics with the long-term characteristics of the actual US economy. We derive the optimal simulated paths toward the steady state. Our simulations confirm the existence of two different relations between body weight and the stock of capital per worker. First, our results are consistent with data on body weight evolution in the USA as the simulated economy shows that the dynamic evolution of average body weight has been monotonous. In other words, given the current degree of peer influence, there is to this date no dynamic Kuznets curve pattern for obesity in the USA. By contrast, we find the existence of a static Kuznets curve for the USA: the steady state level of average body weight increases with the average stock of capital up to a level of 186.5 pounds, corresponding to a stock of capital per worker 25% higher than its the baseline, and decreases thereafter. Those results imply that the US economy is on a path that yields a steady state average body weight currently below the tipping point of the Kuznets curve. Additionally, those results suggest that steady state body weight starts being inversely related to wealth when individual wealth reaches 25% above the average wealth in the US, and is positively related to wealth below this threshold. Second, we conduct a sensitivity analysis. It highlights that the dynamic relation between weight and the per worker capital stock does not exhibit a Kuznets curve pattern for a wide range of elasticities of substitution between food consumption and effective exercise. For very high values of the degree of peer influence, we obtain a simulated dynamic obesity Kuznets curve, which confirms the role of the dynamic peer effect in limiting and potentially inverting body weight growth.

The rest of the paper is structured as follows. In Section 2, we present the model and provide analytical results. In Section 3, we provide numerical results. In Section 4, we conclude and discuss policy implications of our work.

2 Model

2.1 The economy

We build a continuous time dynamic general equilibrium model for a closed economy in which the capital accumulation technology exhibits decreasing returns. There is a large number of firms and households, the respective number of which is normalized to unity. Households derive utility from two types of consumption: fast-food consumption that does not require time, and exercise-related consumption that requires time and is affected by peer effects. In our base model, households maximize utility subject to a dynamic capital accumulation constraint, and body weight is the result of optimal food and exercise choices. We discuss the case when the effect of net calorie intake on body weight gain is endogenized in Section 3.3. In what follows, the time index t is suppressed, unless needed for clarity.

2.1.1 Time-consuming consumption

First, the representative individual distinguishes between two types of goods, those that do not require time, C and those that require time, X. Specifically, C can be thought of as fast-food or junk-food consumption, which requires almost no preparation time. So in our model, it denotes a standard consumption good that does not require time. The variable X can be thought of as exercise. Although our model applies to a broader framework than junk food and exercise, in order to provide clear intuitions in what follows, we simply refer to C as food consumption and X as time spent exercising.

Second, we introduce endogenous labor in the model. Individuals are endowed with one unit of time, used for endogenous labor N, endogenous exercise X, and exogenous sedentary leisure $\bar{S}$ (such as sleeping or watching television). As a consequence:

$$1 = N + X + \bar{S}\,. \tag{1}$$

To simplify the notation, we write that the amount of time that is not spent on sedentary leisure $\bar{L} = 1 - \bar{S}$, such that:

$$\bar{L} = N + X \tag{2}$$

As a consequence, an individual's flow budget constraint accounts for both work time and consumption expenditure related to exercise:

$$\dot{K} = rK + w\left(\bar{L} - X\right) - p_C C - p_X X\,, \;\; p_X, p_C > 0\,, \tag{3}$$

where w is the wage rate, r denotes the interest rate, and p_C and p_X are the respective prices of C and X.

2.1.2 Peer influence

Individuals are influenced by peers when choosing to exercise. We introduce a reference level of exercise, $\bar{X}$, to take into account such peer influence. In our model, the impact of the reference level of exercise is captured by *effective* exercise $\hat{X}$, which differs from absolute exercise X according to the standard subtractive specification (Ljungqvist and Uhlig, 2000):[6]

$$\hat{X} = X - \varepsilon\left(k\right)\bar{X}\,, \quad 0 \leq \varepsilon\left(k\right) \leq 1, \tag{4}$$

where $k \equiv K/N$ denotes aggregate wealth per unit of labor (roughly, capital per worker), which is exogenous for an individual. The reference level $\bar{X} \equiv X/1$ is given by average exercise expenses (aggregate exercise expenses, with the population size equaling unity). It is endogenously determined in our model, but it is exogenous from an individual's point of view (as indicated by the upper bar). The degree (strength) of peer influence is captured by function $\varepsilon\left(k\right)$. When $\varepsilon\left(k\right) = 0$, individuals are not influenced by peers, and effective exercise equals absolute exercise. When $\varepsilon\left(k\right)$ is high, effective exercise is low, and the marginal utility of X is high. The formulation of peer effects is similar to Mathieu-Bolh and Wendner's (2020) in the sense that it includes an exogenous and an endogenous element. We use the following standard functional form to describe the degree of peer influence:

$$\varepsilon(k) = 1 - e^{-\kappa k}, \quad \kappa > 0. \tag{5}$$

The static element κ yields a property called the static peer effect. In our model, it means that, given the stock of capital k, the higher the parameter κ, the more an individual cares about exercise. The dynamic element yields a property that we call the dynamic peer effect. It captures that a higher stock of capital — either built over time due to economic growth, or observed at a given point in time among different countries

[6] This specification of status preferences is prevalent throughout the literature. Formulating it as a multiplicative function (Gali 1994) is also possible and yields essentially equivalent results.

or population subgroups — endogenously increases peer effects :

$$\frac{\partial\varepsilon(k)}{\partial k} > 0\,. \tag{6}$$

Tying peer effects to economic development means that over time, as a country develops, individuals become on average more influenced by peers' exercise behavior, ceteris paribus.

2.1.3 Body weight

The choices of C and X have an impact on body weight change $\dot{W}$. We connect weight gain to net energy intake, the difference between energy intake and expenditure (described in a general manner by Schofield, 1985). Energy intake is a function of food consumption. We introduce a modification in the Schofield equation to take into consideration the role of exercise, work and sedentary leisure. Recall that the usual Schofield equation is: $\dot{W} = \lambda_C C - \lambda_W W$, where the parameter $\lambda_C > 0$ represents the energy density of food (measured in joules per unit of food consumed), and $\lambda_W > 0$ reflects a metabolic rate (measured in joules per unit of weight). In this expression, calorie expenditure is a fixed proportion λ_W of body weight W. Implicitly, calorie expenditure is measured for a unit of time of one, which can be one year or one day, and each type of activity during this unit of time exerts the same amount of calories. By contrast, in our model, we take into consideration that individuals allocate one unit of time to activities that exert different amounts of calories. This unit of time is spent in exogenous sedentary leisure $\bar{S}$, endogenous exercise X and labor N. Therefore, we re-write the Schofield equation as:

$$\dot{W} = \lambda_C C - \frac{\left(\lambda_S \bar{S} + \lambda_X X + \lambda_N N\right)}{N} W. \tag{7}$$

In this expression, $\lambda_S \bar{S}$ represents the basal metabolic rate (BMR), which is basic energy expenditure to maintain the functioning of a body at rest. The terms $\lambda_X X$ and $\lambda_N N$, with $\lambda_X > 0$ and $\lambda_N > 0$, denote the extent to which time spent on exercise and labor reduces net energy. Note that λ_C is a rate in front of the variable C. In the same way, the term in front of W is expressed as a rate. For that reason, $\lambda_S \bar{S} + \lambda_X X + \lambda_N N$ is divided by N (since W is expressed in total terms). While sedentary leisure $\bar{S}$ is fixed and proportional to weight, calorie expenditure associated to non-sedentary leisure and work $\lambda_X X + \lambda_N N$ vary with individuals' choices. Since $N = 1 - \bar{S} - X$, it is straightforward that when individuals choose to exercise more, they spend relatively fewer calories at work.

2.1.4 Preferences and optimal choices

Individuals face a constrained intertemporal optimization problem that is described as follows. Instantaneous utility is given by the strictly concave and twice continuously differentiable function:

$$U(C, \hat{X}, W) = u(C, \hat{X}) - v\left[(W - W^*)^2\right]\,. \tag{8}$$

Both sub-utility functions u and v are strictly increasing in their respective arguments. The intertemporal utility function is:

$$\int_{t=0}^{\infty} U(C, \hat{X}, W) e^{-\rho\tau} d\tau\,, \tag{9}$$

where $\rho > 0$ is the constant rate of time preference. Utility positively depends on food consumption and exercise. An exercise reference level $\bar{X}$ increases marginal utility of exercise. We account for the fact that body weight in excess or below the healthy norm, W^*, causes dis-utility. Considering that individual and average weight are equal *in equilibrium*, this formulation captures obesity related externalities and justifies considering policy interventions discussed in the conclusion. However, weight is not a choice variable in our model, so conspicuous behavior is solely reflected in individuals' food consumption and exercise choices.[7] Given the DOP, $\varepsilon(\bar{k})$, and (7), individuals choose C and $\hat{X}$, to maximize (9), subject to their initial endowment of wealth $K_0 > 0$, their flow budget constraint (combining (4) and (3)):

$$\dot{K} = rK + w\bar{L} - \hat{p}_X \varepsilon\left(\bar{k}\right)\bar{X} - p_C C - \hat{p}_X \hat{X}\,, \tag{10}$$

and a No-Ponzi-Game (NPG) constraint:

$$\lim_{\tau\to\infty} e^{-R(t,\tau)}K \geqslant 0\,, \tag{11}$$

where $R(t,\tau) = \int_t^\tau r(v)dv$ represents the interest factor, and:

$$\hat{p}_X \equiv w + p_X. \tag{12}$$

Price $\hat{p}_X$ represents the total cost of effective exercise that includes the cost of exercise expenditure and the opportunity cost of exercise.

The model is solved in a standard way relying on a current-value Hamiltonian (See Appendix 7.2). We deduce the following expressions for the growth rates of food consumption and exercise. Noticing that in equilibrium, average exercise expenditure equals individual's exercise expenditure, $\bar{X} = X$, and combining the optimality conditions and the relation between effective and actual exercise (4), we obtain the growth rate of consumption and exercise as (see details in Appendix 7.3):

$$\frac{\dot{C}}{C} = \Omega^C\left(C,\hat{X}\right)(r-\rho) + \Phi^C\left(C,\hat{X}\right)\left(\Delta\frac{\dot{w}}{w}\right)\,, \tag{13}$$

$$\frac{\dot{X}}{X} = \Omega^X\left(C,\hat{X}\right)(r-\rho) + \frac{\dot{\varepsilon}\left(k\right)}{1-\varepsilon\left(k\right)} - \Phi^X\left(C,\hat{X}\right)\left(\Delta\frac{\dot{w}}{w}\right)\,. \tag{14}$$

The function Δ is such that $0 < \Delta \equiv \frac{w}{w+p_X} < 1$ (implying that $\frac{\partial\Delta}{\partial w} > 0$, and $\frac{\partial\Delta}{\partial p_X} < 0$). We define the following elasticities: $\Omega^C\left(C,\hat{X}\right) = \frac{e_{\hat{X}\hat{X}} - e_{C\hat{X}}}{-e_{CC}e_{\hat{X}\hat{X}} + e_{C\hat{X}}e_{\hat{X}C}}$, $\Omega^X\left(C,\hat{X}\right) = \frac{e_{CC} - e_{\hat{X}C}}{-e_{CC}e_{\hat{X}\hat{X}} + e_{C\hat{X}}e_{\hat{X}C}}$, $\Phi^C\left(C,\hat{X}\right) = \frac{e_{C\hat{X}}}{-e_{CC}e_{\hat{X}\hat{X}} + e_{C\hat{X}}e_{\hat{X}C}}$, and $\Phi^X\left(C,\hat{X}\right) = \frac{e_{CC}}{-e_{CC}e_{\hat{X}\hat{X}} + e_{C\hat{X}}e_{\hat{X}C}}$, with $e_{CC} = (U_{CC}C/U_C)$, $e_{C\hat{X}} = \left(U_{C\hat{X}}\hat{X}/U_C\right)$, $e_{\hat{X}C} = \left(U_{\hat{X}C}C/U_{\hat{X}}\right)$, $e_{\hat{X}\hat{X}} = \left(U_{\hat{X}\hat{X}}\hat{X}/U_{\hat{X}}\right)$.

The difference between the growth rate of food consumption and the growth rate of exercise expenditure is therefore expressed as:

$$\frac{\dot{C}}{C} - \frac{\dot{X}}{X} = \underbrace{\left[\Omega^C\left(C,\hat{X}\right) - \Omega^X\left(C,\hat{X}\right)\right](r-\rho)}_{ECE} + \underbrace{\left[\Phi^X\left(C,\hat{X}\right) + \Phi^C\left(C,\hat{X}\right)\right]\left(\Delta\frac{\dot{w}}{w}\right)}_{ROC} - \underbrace{\frac{\dot{\varepsilon}\left(k\right)}{1-\varepsilon\left(k\right)}}_{DPE} \tag{15}$$

The growth rate of food consumption differs from the growth rate of exercise expenditure due to three terms. The first term represents Elasticities for Consumption and Exercise (ECE). It includes two elasticities,

[7] We provide a discussion on calorie consciousness in Subsection 3.3.

respectively $\Omega^C\left(C,\hat{X}\right)$ and $\Omega^X\left(C,\hat{X}\right)$. The second term represents the Rising Opportunity Cost of exercise (ROC) and the third term represents the dynamic peer effect (DPE). Note that accounting for the fact that exercise is a consumption expenditure influences the ROC through two channels. One channel operates through $\Phi^C\left(C,\hat{X}\right) < 0$, which denotes that exercise is an expenditure using up resources that cannot be allocated to food consumption. Other things equal, it decreases the growth rate of food consumption and limits the ROC. The other channel operates through p_X and lowers $\Delta \equiv \frac{w}{w+p_X}$. Other things equal, it decreases the importance of ROC related to wage growth. The ultimate impact involves general equilibrium effects that will be accounted for in the next sections.

Proposition 1: *For all forms of utility functions, the difference between the growth rate of consumption and the growth rate of exercise can be positive or negative as the DPE is an offsetting force to the ROC.*

Proof: See Appendix 7.4.■

Thus, the term ECE is neither specific to our assumption that exercise is both a consumption and a time expenditure, nor to our assumption that exercise is affected by peer behavior. By contrast, the terms DPE and ROC are specific to our model and are present for all utility's functional forms. For that reason, in what follows, we will focus on the roles of DPE and ROC. On their own, those terms cause a wedge between the growth rates of consumption and exercise, and generate the pattern for body weight gain. This mechanism is at the core of our results and holds for all forms of utility functions.

2.2 Firms

A unit mass of competitive firms produces a homogeneous output Y. The production process is described by a Cobb-Douglas production function: $Y = F(K,N) = K^\eta N^{1-\eta}$, where $0 < \eta < 1$ denotes the capital elasticity of production. Factors are paid their respective marginal products:

$$\frac{\partial F(K,N)}{\partial K} = r + \delta, \quad \frac{\partial F(K,N)}{\partial N} = w\,, \tag{16}$$

where $\delta \geq 0$ denotes the rate of depreciation. We introduce a normalization (per unit of labor): $y \equiv Y/N$. Noting that $k = K/N$, by homogeneity of degree 1, we can write:

$$y = F(k,1) \equiv f(k) = k^\eta\,. \tag{17}$$

The first-order conditions (16) then become:

$$r(k) = f'(k) - \delta\,, \quad w(k) = f(k) - k\,f'(k)\,. \tag{18}$$

A linear production process transforms total consumption into food consumption and exercise consumption. Output can be used for either investment I or consumption such that $Y = p_C C + p_X X + I$.

2.3 Equilibrium

Definition (Equilibrium) A competitive equilibrium is a price vector (r, w, p_C, p_X) and an attainable allocation for all $t \geq 0$, such that:

1. Individuals choose feasible streams of C, X, K, to maximize intertemporal utility, given the stream of price vectors, initial wealth endowments, the DOP, and average capital.

2. Firms choose K and N in order to maximize profits, given the price vector.

3. All markets clear. Specifically: $\dot{K} = Y - p_C C - p_X X - \delta K$, the goods market clears; the capital

market clears, and $N = \bar{L} - X$, the labor market clears.

4. Reference levels are: $\bar{X} = X$.

To study stability and ultimately enable comparisons between economies or population cross sections, we express the dynamic system in per unit of labor terms, such that $c \equiv C/N$, $x \equiv X/N$, and $\mathrm{w} \equiv W/N$. Furthermore, we express the dynamic system as a function of x and k. Noting that $x = X/N = X/(\overline{L} - X)$, we can re-write $X = x(\bar{L} - X)$, hence, $X = [x/(1+x)]\,\bar{L}$. Thus $X = X(x)$. Next, consider that $\hat{X} = (1 - \varepsilon(k))X(x)$ in equilibrium. Thus, $\hat{X} = \hat{X}(x,k)$. Finally, dividing (30) by (31) (see the appendix), the resulting intratemporal first-order condition $U_C(C,\hat{X})/U_{\hat{X}}(C,\hat{X}) = p_C/\hat{p}_X(k)$ implicitly defines a relationship $C(\hat{X}(x,k),k)$. Since the arguments $\left(C,\hat{X}\right)$ can also be written in terms of (x,k), $\Omega^i(C,\hat{X}) = \Omega^i(x,k)$ and $\Phi^i(C,\hat{X}) = \Phi^i(x,k)$, $i = C, X$. Recall that: $\Delta = w/(p_X + w)$ and $\hat{p}_X = p_X + w$. Since w depends on k, we write $\Delta = \Delta\,(k)$. The comparison term $\varepsilon(k)$ is specified according to (5).

The dynamic system in per unit of labor terms becomes (see Appendix 7.5 for details):

$$\frac{\dot{k}}{k} = \left[1 - x\left[\kappa k - \Phi^X(x,k)\,\eta\Delta(k)\right]\right]^{-1}\left[x\,\Omega^X(x,k)\,(f'(k) - \delta - \rho) + \frac{f(k)}{k} - \delta - \frac{1}{k}\,(p_C c(x,k) + p_X x)\right], \tag{19}$$

$$\frac{\dot{x}}{x} = (1+x)\left[\Omega^X(x,k)\,(f'(k) - \delta - \rho) + \left(\kappa k - \Phi^X(x,k)\,\Delta(k)\,\eta\right)\frac{\dot{k}}{k}\right]. \tag{20}$$

Therefore, the macroeconomic equilibrium gives rise to a dynamic system in two dimensions: k and x. Indeed, the dynamic system is separable in w, since the dynamic variables k and x affect body weight w, but w does not affect k and x, which is to be expected since weight is not a decision variable.[8] The dynamic system in normalized variables is given by (19) – (20): $\dot{k} = \dot{k}(k,x)$; $\dot{x} = \dot{x}(k,x)$.

We separately determine the change in body weight per unit of labor over time and steady state body weight. The normalized Schofield equation, also expressed with normalized variables, reads (see Appendix 7.6):

$$\frac{\dot{\mathrm{w}}}{\mathrm{w}} = \lambda_C\frac{c(x,k)}{\mathrm{w}} - (\lambda_S\bar{s}\,(x) + \lambda_X x + \lambda_N) + \Omega^X(x,k)\,(f'(k) - \delta - \rho) + \left(\kappa k - \Phi^X(x,k)\,\eta\Delta(k)\right)\frac{\dot{k}}{k}, \tag{21}$$

where consumption $c(x,k)$ is derived from the intratemporal optimality condition (ratio of (30) and (31) in the appendix), and solely depends on k and x, and where $\bar{s} = \frac{\bar{S}}{N}$. Since N is endogenous, and depends on X, which depends on x, $\bar{s} = \bar{s}\,(x)$.

A steady-state equilibrium is an equilibrium for which $\dot{k} = \dot{x} = 0$. Let k^* denote the steady state value of k, and $x^* = x\,(k^*)$, $w^* = w(k^*)$, $\hat{p}_X^* = p_X + w^*$, and $c^* = c(x^*, k^*)$. Considering the dynamic system (19) – (20), the steady state is described by the following system (see Appendix 7.9):

$$k^* = f'^{-1}(\delta + \rho)\,; \tag{22}$$

$$x^* = \frac{f(k^*) - \delta k^*}{p_X + p_C c(x^*, k^*)/x^*}, \tag{23}$$

where $f'^{-1}(.)$ denotes the inverse function of $f'(.)$. Equation (22) follows from our model-equivalent of the Keynes-Ramsey rule (equation (20)). The term $c(x^*, k^*)/x^*$ is implicitly given by dividing (30) by (31),

[8] Notice the different fonts for weight (w) and wage (w).

which gives $U_C(C,\hat{X})/U_{\hat{X}}(C,\hat{X}) = p_C/\hat{p}_X(k)$. In case $u(C,\hat{X})$ is homothetic, the left-hand side is a function of $(C/\hat{X}) = c/[x(1-\varepsilon(k)]$. By strict concavity, an inverse function exists ($U_C/U_{\hat{X}}$ as a function of $C/\hat{X}$ is one to one). In this case, c^*/x^* is a function of k^*, allowing us to express x^* *explicitly.* [9]

As a consequence, neither our static nor our dynamic positionality effect (DPE) impact the steady state level of k. Equation (23) determines the steady-state share of output to be devoted to exercise, which increases with the degree of peer influence $\varepsilon(k^*)$. As $f'(k)$ is a strictly monotonous function, there exists only one value k^* satisfying (22). Therefore, the steady state (k^*, x^*) is unique. Similarly to the standard neoclassical growth model, since there is one predetermined and one jump variable, the unique steady state is a saddle point.

Once x^* and c^* are determined, we deduce the steady state body weight per unit of labor w*:

$$\mathrm{w}^* = \left(\frac{\lambda_C c(x^*, k^*)}{\lambda_S \bar{s}\,(x^*) + \lambda_X x^* + \lambda_N}\right). \tag{24}$$

3 Main theoretical results

In the theoretical section, in order to derive straightforward analytical results, we employ a CES utility function (such as 35). Considering that the intratemporal elasticity of substitution plays no qualitative role specific to the model, we assume $\zeta = 0$. In this case, where $1/\gamma$ is the intertemporal elasticity of substitution and $\alpha > 0$ represents the taste for food consumption relative to effective exercise consumption, $\Omega^C = \Omega^X = 1/\gamma$, $\Phi^C = -(1-\alpha)(1-\gamma)/\gamma$, $\Phi^X = (1-\alpha(1-\gamma))/\gamma > 0$ and $\Phi^X + \Phi^C = 1$. Recall that it means that the term ECE equals zero and only the effects specific to our model, DPE and ROC, remain in place. In the steady state the intertemporal elasticity of substitution plays no role either, so γ can take any value without altering our results. We complement our theoretical results with a numerical section, in which we present dynamic and steady state quantitative results for a range of intra and intertemporal elasticities of substitution with CES utility (see Section 4).

3.1 Dynamic obesity Kuznets curve

In what follows, we show that the two opposing effects, DPE and ROC, can produce a dynamic Kuznets curve pattern for obesity. We also explain the puzzling fact that high income earners may increase exercise expenditure despite its rising opportunity cost.

Using the functional form (5), in normalized variables, the DPE and ROC are re-expressed as:

$$DPE = \frac{\dot{\varepsilon}\,(k)}{1-\varepsilon\,(k)} = \kappa\dot{k}\,; \tag{25}$$

$$ROC = \left(\underbrace{\Phi^X + \Phi^C}_{=1}\right)\Delta(k)\frac{\dot{w}}{w} = \frac{1}{\hat{p}_X}\,(-kf''(k))]\dot{k}\,,, \tag{26}$$

[9] For example, with constant elasticities of substitution in (35), $c^*/x^* = \alpha/(1-\alpha)\,(\hat{p}_X\,(k^*)\,/p_C)\,(1-\varepsilon(k^*))$, and the steady state value of x becomes: $x^* = \frac{f(k^*)-\delta k^*}{p_X + \frac{\alpha}{1-\alpha}\hat{p}_X(k^*)(1-\varepsilon(k^*))}$.

Considering (15), the proof of Proposition 1, and that $\frac{\dot{X}}{X} - \frac{\dot{C}}{C} = \frac{\dot{x}}{x} - \frac{\dot{c}}{c}$, we have:

$$\frac{\dot{c}}{c} - \frac{\dot{x}}{x} = \underbrace{\frac{1}{\hat{p}_X}\left(-kf''(k)\right)\dot{k}}_{ROC} - \underbrace{\kappa\dot{k}}_{DPE}. \tag{27}$$

We can now shed light on the difference between the growth rates of food consumption c and exercise x in equilibrium.

Proposition 2: *In a growing economy ($\dot{k} > 0$), for a low level of k, $DPE < ROC$ and $\dot{x}/x < \dot{c}/c$. As k rises, there exists a $\underline{k}(\kappa)$ such that for all $k > \underline{k}(\kappa)$, $DPE > ROC$ and $\dot{x}/x > \dot{c}/c$.*

Proof: See Appendix 7.7.■

Corollary 1: *In a growing economy ($\dot{k} > 0$), for a high level of k, body weight growth eventually becomes negative.*

Proof: See Appendix 7.8.■

Proposition 2 helps us explain the evolution of obesity that goes with economic development as coming from a change in preferences connected to social status. The intuition is that peer effects with respect to exercise are higher in the future than in the present. Consequently, ceteris paribus, the marginal utility of X increases over time. In response, individuals shift X from the present to the future, which implies a higher growth rate of exercise than in the absence of peer effects. For low levels of economic development, Proposition 2 predicts that the growth rate of c exceeds the growth rate of x (note that $\frac{\dot{X}}{X} - \frac{\dot{C}}{C} = \frac{\dot{x}}{x} - \frac{\dot{c}}{c}$). As a consequence, the ratio c/x and body weight increase. At some point of economic development, as the stock of capital per unit of labor exceeds a certain threshold, Proposition 2 predicts that the growth rate of x exceeds the growth rate of c. As a consequence, the ratio c/x and body weight decrease. Since the evolution of body weight is tied to the evolution of c/x, it is easy to show that the growth rate of body weight eventually decreases. Therefore, Proposition 2 and its corollary provide an explanation for the empirically estimated dynamic obesity Kuznets curve.

Corollary 2: *In a growing economy, if we ignore the DPE ($\kappa = 0$), $\dot{x}/x < \dot{c}/c$, $\forall k$.*

Proof: Straight from ((27)) and Proposition 1, in the absence of the DPE ($\kappa = 0$), the difference between $\frac{\dot{x}}{x} - \frac{\dot{c}}{c}$ is always negative, so that exercise expenses grow at a slower pace than food consumption.■

A consequence of Corollary 2 is that without the DPE (DPE=0), the ratio c/x and body weight would never decrease. This would yield two counterfactual results. It would imply that exercise expenses always grow at a lower pace than food consumption, and that obesity always rises and never exhibits a Kuznets curve.

Additionally, ignoring that exercise is an expenditure would be equivalent to setting $p_X = 0$. This would decrease the relative cost of exercise and the coefficient Δ, directly increasing the ROC ceteris paribus. It would also modify the optimal choice of exercise relative to food consumption and therefore influence capital accumulation, and the marginal product of labor, which indirectly influences both DPE and ROC. The effects of relaxing the assumption of $p_X > 0$ on the dynamic Kuznets curve can therefore not be made explicit but will be studied in the numerical section.

3.2 Static obesity Kuznets curve

In what follows, we draw a parallel between mechanisms operating for the dynamic obesity Kuznets curve and the static obesity Kuznets curve. The following comparative static analysis can be considered a cross-sectional analysis, comparing countries or individuals with different steady state wealths k^*. It can also be considered a comparative static analysis of a single country for which a change in a technology or preference parameter causes a change in k^*.

In the steady state, the DPE and ROC are re-expressed as (see Appendix 7.10 for details):

$$ROC^* = \Delta\left(k^*\right)\frac{dw^*}{w^*} = \frac{\eta(1-\eta)\left(k^*\right)^{\eta-1}}{(1-\eta)\left(k^*\right)^{\eta}+p_X}$$

$$DPE = \frac{d\varepsilon(k^*)}{(1-\varepsilon(k^*))} = \kappa$$

The difference between the change of c^* and the change of x^* is:

$$\frac{dc^*}{c^*} - \frac{dx^*}{x^*} = \left[\underbrace{\frac{\eta(1-\eta)\left(k^*\right)^{\eta-1}}{(1-\eta)\left(k^*\right)^{\eta}+p_X}}_{ROC^*} - \underbrace{\kappa}_{DPE}\right], \tag{28}$$

where ROC^* represents the higher opportunity cost of time spent on exercise that goes with a higher marginal product of labor associated with a higher steady state capital stock, and DPE represents the dynamic peer effect that denotes the increase in peer effects associated with a higher steady state capital stock. The terms ROC^* and DPE^* are the steady state equivalents of the terms ROC and DPE presented in the dynamic setting. From this expression, we deduce Proposition 3, which is the steady state equivalent of Proposition 2.

Proposition 3: *For a low level of k^*, $DPE^* < ROC^*$ and $\frac{dx^*}{x^*} < \frac{dc^*}{c^*}$. As k^* is higher, there exists a $\underline{k^*}(\kappa)$ such that for all $k > \underline{k}^*(\kappa)$, $DPE^* > ROC^*$ and $\frac{dx^*}{x^*} > \frac{dc^*}{c^*}$.*

Proof: See Appendix 7.11.■

The comparison of body weight for different wealth levels is obtained by totally deriving body weight (See (42) in the appendix) with respect to k^*, which yields:

$$\frac{d\mathrm{w}^*}{dk^*} = \frac{\lambda_C c^*/x^*}{z^*}\left[\frac{\frac{d(c^*/x^*)}{c^*/x^*} - \frac{dz^*}{z^*}}{dk^*}\right] \tag{29}$$

where $z\left(k^*\right) = \lambda_S \bar{s}\left(x^*\right)/x^* + \lambda_X + \lambda_N/x^*$ represents total calorie expenditure divided by exercise expenditure.

Corollary 3: *If we ignore the fact that exercise is a type of consumption expenditure, ROC^* is larger and it is less likely that $DPE^* > ROC^*$ and $\frac{dx^*}{x^*} > \frac{dc^*}{c^*}$.*

Proof: straightforward from Proposition 3 and the term ROC^* that unambiguously decreases when p_X increases.■

Therefore, exercise as an expenditure increases ROC^* and the gap between the growth rates of consumption and exercise, limiting the possibility of a static Kuznets curve.

Proposition 4: *For high values of k^*, $\frac{d\mathrm{w}^*}{dk^*} < 0$ if $\kappa > -\underbrace{\frac{dz^*}{z^*}}_{(+)}$, and positive otherwise.*

Proof: See Appendix 7.12.■

As shown in the proof, for high values of k^* the term $\frac{d(c^*/x^*)}{c^*/x^*}$ converges toward $-\kappa$. At the same time, $\frac{dz^*}{dk^*}/z^* < 0$, which implies that the ratio of total calorie expenditure over exercise decreases. For for high values of k^*, the percentage change in c^*/x^* is negative and converges to the negative of the degree of peer influence, which has a negative effect on body weight. However, the percentage change in z^*, the ratio of total calorie expenditure over exercise decreases, which has a positive effect on body weight. Equivalently, when the degree of peer influence is large enough, the decrease in the ratio of calorie intake over exercise expenditure is large and results in lower body weight as long as it dominates the effect of the decrease in the ratio of total calorie expenditure over exercise.

Corollary 4: *For high values of k^*, if we ignore the DPE ($\kappa = 0$), $\frac{d\mathrm{w}^*}{dk^*} > 0$.*

Proof: straightforward from Proposition 4, $0 < \underbrace{-\frac{dz^*}{z^*}}_{(+)} \Rightarrow \frac{d\mathrm{w}^*}{dk^*} > 0$.■

The DPE generates substitution toward exercise and drives the negative correlation between the stock of capital and body weight for high values of steady state capital stock. In the absence of the DPE^*, for high values of steady state capital stock, the main effect is the ROC^* that unambiguously results in a decrease of exercise and a higher steady state body weight.

Therefore, the introduction of dynamic peer effects helps explain why, despite a higher opportunity cost of exercise, rich individuals may exercise more than poor individuals. With Proposition 2 and Corollary 1, we showed that the evolution of the stock of capital over time generates ROC and DPE, eventually yielding an obesity Kuznets curve. With Proposition 3, we explain how differences in ROC^* and DPE^* are tied to different steady state capital stocks between poor and rich countries (or individuals). With Corollary 3, we show that acknowledging that exercise is a consumption expenditure constitutes a mechanism that raises the ROC^* and competes with the DPE^* . Corollary 4 is consistent with evidence presented in the introduction that $d\mathrm{w}^*/dk^* > 0$ for poor countries (or individuals) and $d\mathrm{w}^*/dk^* < 0$ for rich countries (or individuals), and suggests that dynamic peer effects associated with the consumption of time consuming goods plays a larger role for rich than poor countries (or individuals).

3.3 Calorie consciousness

In this section, we study the behavior of individuals who are both weight conscious and calorie conscious. Individuals internalize the net effect of calorie intake on weight gain (equation (7)), accounting for the fact that labor and exercise choices are endogenous (equation (1)) and that exercise choices are influenced by peer effects (equation (4)). The formulation of the problem is consistent with Mathieu-Bolh and Wendner (2020) and presented in Appendix 7.13.

Proposition 5: *When overweight individuals are calorie conscious, the ratio $\frac{C}{\hat{X}}$ is lower than if they are calorie unconscious.*

Proof: See Appendix 7.14.

As expected, calorie consciousness reinforces the choice of exercise over consumption and is likely to result in lower equilibrium body weight. The Kuznets curve remains the reflection of competing rise in opportunity cost of exercise and peer effects, and calorie consciousness may accelerate the shift from a positive to a negative income obesity relation or shift the Kuznets curve down.

4 Numerical results

We supplement the qualitative analysis with a quantitative analysis relying on numerical simulations. Our numerical simulations illustrate our theoretical results and give a sense of magnitudes regarding the role of peer influenced on exercise expenditures for the steady state and dynamic Kuznets curves.[10] We use data from the American time use survey by the Bureau of Labor Statistics (BLS), the U.S. Department of Health and Human Services (HHS), the Consumer Expenditure Survey, and the work by Valero-Elizondo (2016), Turnovsky (2000), Barro and Sala-i-Martin (2003), and Burda and Wyplosz (2017) to calibrate the model (see Appendix 7.15).

We simulate steady state body weight for different steady-state levels of the stock of capital per unit of labor to explore the possibility of a static Kuznets curve for obesity in the USA. We also study the evolution of body weight toward its steady state as the stock of capital increases over time to study the possibility of a dynamic obesity Kuznets curve in the USA. Additionally, we conduct sensitivity analysis for the static and dynamic Kuznets curves.

4.1 Baseline scenario

First, we build the curve that connects steady-state body weight to the steady-state capital stock. Recall that in our model, peer effects have an endogenous component tied to the level of capital per unit of labor. In the steady state, the stock of capital is given by exogenous parameters, which are the rates of time preference, depreciation, and the production elasticity of capital. These parameters have an impact on the steady-state capital stock k* and steady-state weight. We simulate the steady-state weights by directly changing k*, going from the baseline steady-state capital stock to two times its value.[11] Since peer effects also have an exogenous component κ related to idiosyncratic differences between individuals or countries, we provide simulations for three different levels of κ, at the baseline value of 0.10 and close to it. The static relation between obesity and the stock of capital per unit of labor is presented on the left graph in Figure 1. Second, we build the curve showing the evolution of body weight over time toward the current steady state. The dynamic relation between obesity and the stock of capital per unit of labor is presented on the right graph in Figure 1.

The current steady state body weight for the US is 185 pounds, which is the starting point for the static relation between body weight and the stock of capital per unit of labor in our baseline scenario. We find the existence of a static Kuznets curve: for the baseline level of κ, the steady state level of average body weight increases with the average stock of capital up to a level of 186.5 pounds, corresponding to a stock of capital per unit of labor 25% higher than its the baseline, and decreases thereafter. The first interpretation of this finding is that the US economy's tipping point of the Kuznets curve is not yet reached. It will be reached once the stock of capital per unit of labor is 25% higher than its baseline in the simulations.

The second interpretation of this result is that the steady state average body weight starts being inversely related to wealth when individual wealth is 25% above the average wealth in the US, and is positively related to wealth below this threshold. Furthermore, when the parameter κ is higher than in the baseline, DPE* is relatively stronger than ROC*. As a consequence, as expected, steady state body weight is lower and the

[10] We rely on Mathematica and use the relaxation algorithm to obtain dynamic results.

[11] To obtain meaningful body weight levels, we normalize the steady state body weight at 185 pounds in the initial steady state.

obesity Kuznets curve is even more concave as individuals choose to exercise more. Thus our simulations also show that exogenous differences in the degree of peer influence between individuals or countries may yield different Kuznets curves.

By contrast, the dynamic evolution of body weight towards its steady state value of 185 points does not show a dynamic Kuznets curve pattern for body weight in our baseline scenario. It means that given the level of κ, the model shows that the increase in the capital stock has so far generated a DPE that has resulted in slowing down the growth rate of body weight but that it has not been sufficient to produce a dynamic obesity Kuznets curve. For both the static and the dynamic relations, the higher κ, the more prevalent peer effects, the lower the level of steady state body weight.

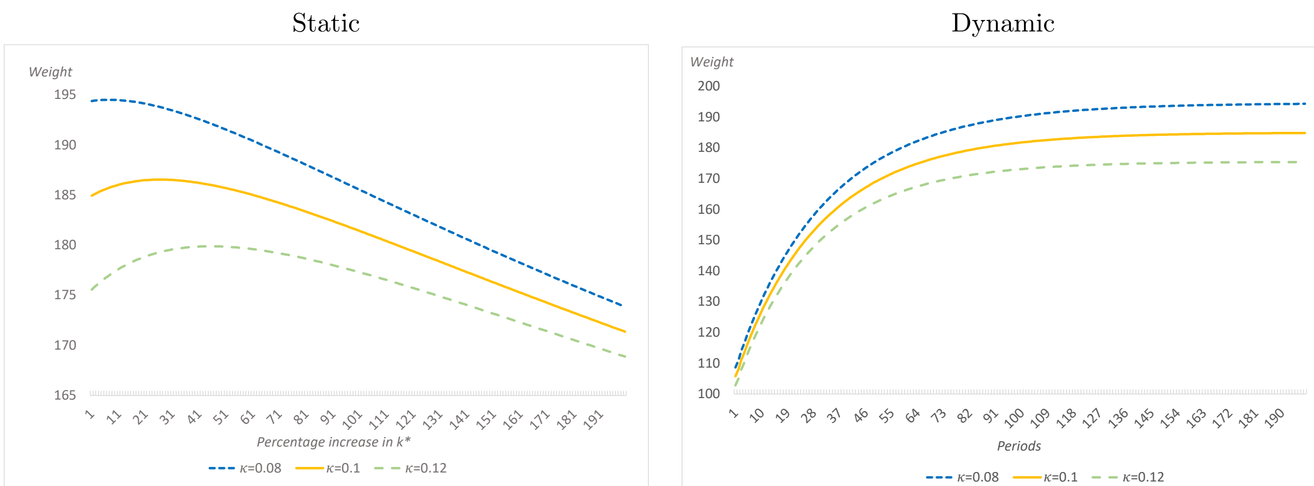

Figure 1: Body weight and capital stock with different degrees of peer influence

The existence of a static Kuznets curve is consistent with results of empirical studies for the USA presented in the introduction. Given the exogenous degree of peer influence κ, the stock of capital per unit of labor would need to be 25 percent higher for the DPE* to be large enough and steady state body weight to decrease. The absence of the Kuznets curve to this date is also consistent with US data showing that obesity has increased over time and its growth rate has slowed down (see Figure A3 in the appendix). The DPE may explain the slowdown of the evolution of obesity in the USA as individuals who are influenced by their peers have allocated more time toward exercise as the economy developed. However this influence has so far been insufficient on its own to produce a decrease in average weight gain.

4.2 Sensitivity analysis

In this subsection, we first show the effect of considering exercise as a consumption expenditure on the static and dynamic Kuznets curves by varying the cost of exercise expenditure from $p_X = 0$ (absence of consumption expenditure related to exercise) up to the parametrized cost of 20.76. Furthermore, in our numerical simulations, recall that the baseline scenario corresponds to unit elasticities, with the parameters being set at $\zeta = 0$ for the elasticity of substitution between food consumption and effective exercise, and

$\gamma = 1$ for the intertemporal elasticity of substitution. We estimate the static and dynamic relations between body weight and the stock of capital per unit of labor with different elasticities of substitution. The full sensitivity analysis is presented in Appendix 7.16. The most striking results are as follows. The dynamic relation between weight and the capital stock does not exhibit a Kuznets curve pattern for a wide range of elasticities of substitution between food consumption and effective exercise. For both the static and dynamic relations, the more food consumption and effective exercise are complements, the more prevalent peer effects, the lower the level of steady state body weight. Peer effects would need to be larger than empirically observed for a dynamic Kuznets curve to occur.

5 Conclusion

Our model expands the theoretical literature to acknowledge the importance of calorie expenditure in maintaining healthy body weights and the fact that preferences change over time. We build and simulate the first theoretical growth model that combines Becker's (1965) theory of the allocation of time and Veblen's (1899) theory of conspicuous leisure, and focus on exercise choices and changing preferences to explain obesity-income patterns.

We show that both a dynamic and a static Kuznets curve for obesity can arise and provide a novel explanation of the mechanisms generating the dynamic and static Kuznets curves. Our dynamic model shows that the difference between the growth rate of consumption and the growth rate of exercise reflects the difference between the rise in the opportunity cost of exercise and the change in peer-influence with respect to exercise. We formally demonstrate the existence of a level of capital per worker for which the growth rate of exercise starts exceeding the growth rate of food consumption. These mechanisms apply to a dynamic environment in which the stock of capital per worker builds up over time and a static environment used for cross-sectional analysis of countries or individuals with different income levels, explored through comparative statics.

Furthermore, we show that ignoring dynamic peer effects with respect to exercise choices would yield a positive correlation between economic development and weight gain at all levels of economic development. By contrast, in the presence of dynamic peer effects with respect to exercise, for high levels of economic development, we show that body weight gain becomes negative as the economy develops over time. The static analysis indicates that for high levels of the steady-state stock of capital per worker, the link between body weight and the steady state capital stock is negative only for relatively high degrees of peer influence.

We supplement the qualitative analysis with numerical simulations. The simulated US economy shows that the dynamic evolution of body weight does not show a dynamic Kuznets curve pattern for obesity. However, we find a static Kuznets curve for the USA: the steady state level of average body weight increases with the average stock of capital up to a level of 186.5 pounds, corresponding to a stock of capital per worker 25% higher than its current steady state level, and decreases thereafter.

We acknowledge a few caveats in our work. Neither our behavioral model, nor our simulations distinguish between men and women, while the data show differences in the income obesity relation between men and women. This task is limited by the lack of empirical data on behavioral differences with respect to food consumption and exercise, and specific to men and women. Notwithstanding these limitations, this study clarifies the impact of peer effects on the relation between income and obesity.

A natural extension of this work is to use our model to study the effect of exercise subsidies. While calorie expenditure is an important factor in weight gain, in the US, government policies aiming at encouraging exercise have been limited. The most recent federal level initiative is the Let's Move program led by former First Lady Michelle Obama. Additionally, while a larger and larger number of employers are offering financial incentives for heathy behavior, small businesses who employ more than half of the private sector workforce do not. Less than five percent of worksites with 50 to 99 employees offer comprehensive workplace health programs. However, Cawley's (2015) literature review, Mukhopadhyay and Wendel (2013), and Goetzel (2016) indicate that physical exercise programs have potential in preventing youth obesity and improving employees' health. It is therefore important to understand the effect of exercise subsidies on obesity, distinguishing between subsidies to consumers as opposed to employers. Our model provides a starting framework for this analysis since it accounts for the fact that the cost of exercise is both an expenditure and an opportunity cost and provides a vehicle to study various types of exercise subsidies. It also suggests that subsidies targeting the price of exercise expenditure (p_X) may have a different quantitative effect from those targeting wages (w) because they affect the ROC in different ways. By lowering p_X to show the role of exercise as an expenditure, we already showed that a subsidy lowering the cost of exercise would result in lower body weight. Exploring the effects of subsidies should be the focus of future investigations.

6 References

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7 Appendix

7.1 Exercise choices and income

Exercise choices differ according to income. First, individual's calorie expenditure through labor is tied to economic development. Based on the U.S. National Health and Nutrition Examination Surveys (NHANES), Church et al. (2011) show that in the early 1960's, almost half the jobs in the private industry in the U.S. used to require at least moderate-intensity physical activity, whereas nowadays, less than 20% of those jobs demand this level of energy expenditure. Since 1960, the estimated mean daily energy expenditure due to work-related physical activity has dropped by more than 100 calories for both women and men. While Lakdawalla et al. (2005) and Lakdawalla et al. (2009) have focused on calorie expenditure related to technological progress and work, we are focusing on calorie expenditure related to leisure time. Our model reflects that when individuals do not spend calories at work, they may chose to exercise during leisure time. Second, there are also important differences in time spent exercising based on income cross-sections. Shuval et al. (2017) find that compared to those making less than \$20,000 per year, those with an annual income of \$75,000 or more engage in 4.6 more daily minutes of moderate to vigorous-intensity physical activity. Higher income earners also exhibit more intense, less frequent weekly patterns of physical activity and more daily sedentary time. The 2008 BLS Spotlight on Statistics covering time spent on sports and exercise, provides insights on differences in the practice of exercise between different income groups. The study indicates the percentage of adults 25 and older who engage in those activities between 2003 and 2006, according to their educational attainment (see Figure A1 in the appendix). It shows that 10 percent of people with less than a high-school diploma engage in those activities, while 23 percent of individuals with a bachelor's degree or higher engage in those activities.

7.2 Optimality conditions

$$\mathcal{H} = U(C, \hat{X}, W) + \mu \left[rK + w\bar{L} - \hat{p}_X \varepsilon\left(\bar{k}\right) \bar{X} - p_C C - \hat{p}_X \hat{X} \right] \,,$$

where μ is the shadow value of saving expressed in utility units. An interior solution regarding the control variables implies:

$$\frac{\partial \mathcal{H}}{\partial C} = U_C - \mu\, p_C = 0 \,, \tag{30}$$

$$\frac{\partial \mathcal{H}}{\partial \hat{X}} = U_{\hat{X}} - \mu\, \hat{p}_X = 0 \,. \tag{31}$$

The canonical equations regarding the state variable K are:

$$\frac{\partial \mathcal{H}}{\partial K} = \mu r = \rho\mu - \dot{\mu}\,, \tag{32}$$

$$\lim_{\tau\to\infty} \mu(\tau) e^{-\rho\tau} K(\tau) = 0, \tag{33}$$

where (33) is the transversality condition, and (32) yields:

$$\frac{\dot{\mu}}{\mu} = -(r-\rho)\,. \tag{34}$$

7.3 Solution to the individual's optimization problem (equations (13) and (14))

Based on the first-order conditions (30), (31), and (32), the intratemporal optimality condition becomes

$$\frac{U_{\hat{X}}(C,\hat{X},W)}{U_C(C,\hat{X},W)} = \frac{u_{\hat{X}}(C,\hat{X})}{u_C(C,\hat{X})} = \frac{p_{\hat{X}}}{p_C},$$

due to separability of the utility function in W. Differentiating the first-order conditions with respect to time yields

$$\frac{\dot{U}_C(C,\hat{X},W)}{U_C(C,\hat{X},W)} = \frac{u_{CC}(C,\hat{X})C}{u_C(C,\hat{X})}\frac{\dot{C}}{C} + \frac{u_{C\hat{X}}(C,\hat{X})\hat{X}}{u_C(C,\hat{X})}\frac{\dot{\hat{X}}}{\hat{X}} = \frac{\dot{\mu}}{\mu} = -(r-\rho),$$

and

$$\frac{\dot{U}_{\hat{X}}(C,\hat{X},W)}{U_{\hat{X}}(C,\hat{X},W)} = \frac{u_{\hat{X}C}(C,\hat{X})C}{u_{\hat{X}}(C,\hat{X})}\frac{\dot{C}}{C} + \frac{u_{\hat{X}\hat{X}}(C,\hat{X})\hat{X}}{u_{\hat{X}}(C,\hat{X})}\frac{\dot{\hat{X}}}{\hat{X}} = \frac{\dot{\mu}}{\mu} + \frac{\dot{\hat{p}}_X}{\hat{p}_X} = -(r-\rho) + \Delta\frac{\dot{w}}{w}.$$

Let e_{ij}, $i,j \in \left\{C,\hat{X}\right\}$ define the elasticities $u_{ij}(i,j)j/u_i$. Then, the above growth rates can be written as (suppressing the arguments of the elasticity functions):

$$e_{CC}\frac{\dot{C}}{C} + e_{C\hat{X}}\frac{\dot{\hat{X}}}{\hat{X}} = -(r-\rho),$$

and

$$e_{\hat{X}C}\frac{\dot{C}}{C} + e_{\hat{X}\hat{X}}\frac{\dot{\hat{X}}}{\hat{X}} = -(r-\rho) + \Delta\frac{\dot{w}}{w}.$$

Considering both equations and collecting terms yields:

$$\frac{\dot{C}}{C} = \left[\frac{e_{\hat{X}\hat{X}} - e_{C\hat{X}}}{-e_{CC}e_{\hat{X}\hat{X}} + e_{C\hat{X}}e_{\hat{X}C}}\right](r-\rho) + \left[\frac{e_{C\hat{X}}}{-e_{CC}e_{\hat{X}\hat{X}} + e_{C\hat{X}}e_{\hat{X}C}}\right]\Delta\frac{\dot{w}}{w},$$

and

$$\frac{\dot{\hat{X}}}{\hat{X}} = \left[\frac{e_{CC} - e_{\hat{X}C}}{-e_{CC}e_{\hat{X}\hat{X}} + e_{C\hat{X}}e_{\hat{X}C}}\right](r-\rho) - \left[\frac{e_{CC}}{-e_{CC}e_{\hat{X}\hat{X}} + e_{C\hat{X}}e_{\hat{X}C}}\right]\Delta\frac{\dot{w}}{w}.$$

Considering the definitions Ω^C, Ω^X, Φ^C and Φ^X we can re-write the above equations as:

$$\frac{\dot{C}}{C} = \Omega^C\left(C,\hat{X}\right)(r-\rho) + \Phi^C\left(C,\hat{X}\right)\Delta\frac{\dot{w}}{w},$$

and

$$\frac{\dot{\hat{X}}}{\hat{X}} = \Omega^X\left(C,\hat{X}\right)(r-\rho) - \Phi^X\left(C,\hat{X}\right)\Delta\frac{\dot{w}}{w}.$$

In equilibrium, $\hat{X} = X(1-\varepsilon(k))$, that is:

$$\frac{\dot{\hat{X}}}{\hat{X}} = \frac{\dot{X}}{X} - \frac{\dot{\varepsilon}(k)}{1-\varepsilon(k)},$$

so:

$$\frac{\dot{X}}{X} = \Omega^X\left(C,\hat{X}\right)(r-\rho) + \frac{\dot{\varepsilon}(k)}{1-\varepsilon(k)} - \Phi^X\left(C,\hat{X}\right)\Delta\frac{\dot{w}}{w}.$$

7.4 Proof of Proposition 1

Straightforward from (15). The ECE includes two elasticities, respectively $\Omega^C\left(C,\hat{X}\right)$ and $\Omega^X\left(C,\hat{X}\right)$, which are different unless preferences are CES, in which case this term disappears. To illustrate the terms Ω^C, Ω^X, Φ^C, Φ^X, we can consider a constant elasticities of substitution specification for the utility function, such that:

$$U(C,\hat{X},W) = \frac{\left[\left(\alpha C^\zeta + (1-\alpha)\hat{X}^\zeta\right)^{1/\zeta}\right]^{1-\gamma}}{1-\gamma} - v\left[(W-W^*)^2\right], \quad 0<\alpha<1,\ \gamma>0,\ \zeta\leq 1\,. \tag{35}$$

where α represents the taste for food consumption relative to effective exercise consumption. The intratemporal elasticity of substitution between C and $\hat{X}$ is given by $1/(1-\zeta)$, while the intertemporal elasticity of substitution (IES) is given by $1/\gamma$. For the whole class of constant elasticities of substitution utility functions, the term $\left[\Phi^X + \Phi^C\right] = 1/(1-\zeta) > 0$ (with $\Phi^C = -(1-\alpha)(1-\gamma)/\gamma < 0$) and $\Omega^C = \Omega^X = 1/\gamma$. That is, in (15), the term ECE equals zero. Therefore, equation (15) indicates that the sign of the rate of change of exercise expenditure is ambiguous, solely depending on the difference between DPE and ROC, which are two positive terms.■

7.5 Derivation of the dynamic system in k and x (equations (19) and (20))

Considering our functional specification of $\varepsilon(k)$,

$$\frac{\dot{\varepsilon}(k)}{1-\varepsilon(k)} = \frac{\varepsilon'(k)k}{1-\varepsilon(k)}\frac{\dot{k}}{k} = (\kappa k)\frac{\dot{k}}{k}.$$

As $\dot{w}/w = \eta\,\dot{k}/k$, and considering that $\hat{X} = \hat{X}(x,k)$ and $C = C(x,k)$ – see Subsection 2.3 – we re-write the growth rate of X:

$$\frac{\dot{X}}{X} = \Omega^X(x,k)(r-\rho) + \left[\kappa k - \Phi^X(x,k)\,\Delta\,\eta\right]\frac{\dot{k}}{k}.$$

As $x = X/N$, $\dot{x}/x = \dot{X}/X - \dot{N}/N$. We note that $\dot{N}/N = -X/(\bar{L} - X)\left(\dot{X}/X\right) = -x\left(\dot{X}/X\right)$. Thus, $\dot{x}/x = (1+x)\dot{X}/X$:

$$\frac{\dot{x}}{x} = (1+x)\left[\Omega^X(x,k)\left(f'(k) - \delta - \rho\right) + \left[\kappa k - \Phi^X(x,k)\,\Delta\,\eta\right]\frac{\dot{k}}{k}\right]. \tag{36}$$

Next, $\left(\dot{k}/k\right) = \left(\dot{K}/K\right) - \left(\dot{N}/N\right) = \left(\dot{K}/K\right) + x\left(\dot{X}/X\right)$. We consider the resource constraint $\dot{K} = f(k)N - \delta K - p_C C - p_X X$:

$$\frac{\dot{k}}{k} = \left(\frac{\dot{K}}{K}\right) + x\frac{\dot{X}}{X} = \left(\frac{f(k)}{k} - \delta - p_C\frac{c}{k} - p_X\frac{x}{k}\right) + x\left\{\Omega^X(x,k)\left(r - \rho\right) + \left[\kappa k - \Phi^X(x,k)\,\Delta\,\eta\right]\frac{\dot{k}}{k}\right\},$$

thus,

$$\frac{\dot{k}}{k}\left\{1 - x\left[\kappa k - \Phi^X(x,k)\,\Delta\,\eta\right]\right\} = \left(\frac{f(k)}{k} - \delta - p_C\frac{c}{k} - p_X\frac{x}{k}\right) + x\,\Omega^X(x,k)\left(r - \rho\right),$$

and as a result:

$$\frac{\dot{k}}{k} = \left\{1 - x\left[\kappa k - \Phi^X(x,k)\,\Delta\,\eta\right]\right\}^{-1}\left[x\,\Omega^X(x,k)\left(f'(k) - \delta - \rho\right) + \frac{f(k)}{k} - \delta - p_C\frac{c(x,k)}{k} - p_X\frac{x}{k}\right]. \tag{37}$$

7.6 Derivation of the Schofield equation with normalized variables (equation (21))

We now derive (21). We rewrite the Schofield equation (38) as:

$$\dot{W} = \lambda_C C - \frac{\left(\lambda_S\bar{S} + \lambda_X X + \lambda_N N\right)}{N}W, \tag{38}$$

$$\frac{\dot{W}}{W} = \lambda_C\frac{C}{W} - \frac{\left(\lambda_S\bar{S} + \lambda_X X + \lambda_N N\right)}{N} = \frac{\dot{\mathrm{w}}}{\mathrm{w}} + \frac{\dot{N}}{N}. \tag{39}$$

Since:

$$\frac{\dot{N}}{N} = -x\frac{\dot{X}}{X} = -\frac{1}{1+x}\frac{\dot{x}}{x},$$

$$\frac{\dot{\mathrm{w}}}{\mathrm{w}} = \lambda_C\frac{C}{N}\frac{N}{W} - \frac{\left(\lambda_S\bar{S} + \lambda_X X + \lambda_N N\right)}{N} + \frac{1}{1+x}\frac{\dot{x}}{x}.$$

Substituting (36) in this expression yields:

$$\frac{\dot{\mathrm{w}}}{\mathrm{w}} = \lambda_C\frac{c}{\mathrm{w}} - \frac{\left(\lambda_S\bar{S} + \lambda_X X + \lambda_N N\right)}{N} + \Omega^X(x,k)\left(f'(k) - \delta - \rho\right) + \left(\kappa k - \Phi^X(x,k)\,\eta(k)\,\Delta(k)\right)\frac{\dot{k}}{k},$$

which is equivalent to:

$$\frac{\dot{\mathrm{w}}}{\mathrm{w}} = \lambda_C\frac{c}{\mathrm{w}} - \left(\lambda_S\bar{s} + \lambda_X x + \lambda_N\right) + \Omega^X(x,k)\left(f'(k) - \delta - \rho\right) + \left(\kappa k - \Phi^X(x,k)\,\eta(k)\,\Delta(k)\right)\frac{\dot{k}}{k}.$$

7.7 Proof of Proposition 2

Throughout, we consider a growing economy, $\dot{k} > 0$, so that the sign of the difference $ROC - DPE$ is determined by :

$$\frac{\dot{c}}{c} - \frac{\dot{x}}{x} = \underbrace{\frac{1}{\hat{p}_X}\left(-kf''(k)\right)\dot{k}}_{ROC} - \underbrace{\kappa\dot{k}}_{DPE}. \tag{40}$$

equivalent to:

$$\frac{\frac{\dot{c}}{c} - \frac{\dot{x}}{x}}{\dot{k}} = \frac{ROC - DPE}{\dot{k}} = \frac{1}{p_X + w}\left(-kf''(k)\right) - \kappa\,. \tag{41}$$

In the presence of a DPE, the sign of this expression is ambiguous, as both terms DPE and ROC are positive. However, while coefficient κ, related to the term DPE, is constant, the term related to ROC changes as k increases. Notice that $\lim_{k\to 0}\left[-k\,f''(k)\right] = \infty$, and $\lim_{k\to 0}\left[1/(w + p_X)\right] = 0$. Likewise, $\lim_{k\to\infty}\left[-k\,f''(k)\right] = 0$ and $\lim_{k\to\infty}\left[1/(w+p_X)\right] = 1/p_X > 0$. That is, given an increase in capital over time $\dot{k} > 0$, ROC approaches infinity for a low level of k, and it approaches zero for a high level of k. Moreover, the ROC is monotonously decreasing as k increases, because w increases and $\left[-k\,f''(k)\right]$ monotonously decreases: $\partial[-k\,f''(k)]/\partial k < 0$. As a consequence, given $\kappa > 0$, and given an increase in capital over time $\dot{k} > 0$, the sign of $(ROC - DPE)$ is positive for low k and negative for high k.■

7.8 Proof of Corollary 1

The normalized Schofield equation is reexpressed as:

$$\frac{\dot{\mathrm{w}}}{x} = \left\{\lambda_C \frac{c}{x} - \left(\lambda_S \bar{s}\,(x) + \lambda_X x + \lambda_N\right)\frac{\mathrm{w}}{x} + \left(f'(k) - \delta - \rho\right)\frac{\mathrm{w}}{x} + \left(\kappa k - \eta(k)\Delta(k)\right)\frac{\dot{k}}{k}\frac{\mathrm{w}}{\mathrm{x}}\right\}. \tag{42}$$

Based on Proposition 2 and its proof, given $\dot{k} > 0$ (that is, $k < k^*$), when k is large, $\frac{\frac{\dot{x}}{x} - \frac{\dot{c}}{c}}{\dot{k}} \to \kappa$ and therefore $\frac{c}{x} \to 0$. Furthermore, for k is large, $f'(k) - \delta - \rho \to 0$ and $\left(\kappa k - \eta(k)\Delta(k)\right)\frac{\dot{k}}{k} \to 0$. As a consequence, $\frac{\dot{\mathrm{w}}}{x} \to -\left(\lambda_S \bar{s}\,(x) + \lambda_X x + \lambda_N\right)\frac{\mathrm{w}}{x} < 0$. Indeed, this term represents the negative of per worker calorie expenditure from all activities (sedentary leisure, exercise and work) divided by exercise. As a consequence, the growth rate of body weight becomes negative when k is large.■

7.9 Steady-State equilibrium x* and k*

In the steady state $f'(k^*) = \delta + \rho$. As $f(k)$ is an increasing and strictly concave function, $f'(k)$ is monotone, and there exists an inverse function $f'^{-1}(.)$. An asterisk denotes a steady state value. Then:

$$k^* = f'^{-1}(\delta + \rho).$$

We express the intratemporal trade-off between exercise and food consumption as:

$$p_C c^* = (p_X + w^*)\frac{\alpha}{1-\alpha}(1 - \varepsilon(k^*))x^*\,.$$

From (19), we know that:

$$f(k^*) - \delta k^* = p_C c^* + p_X x^* = x^* \left(p_X + p_C \frac{c^*}{x^*} \right) .$$

Combining both equations yields an implicit steady-state relationship between x and k:

$$f(k^*) - \delta k^* = x^* \left[p_X + \frac{\alpha}{1-\alpha} \left(p_X + w^* \right) \left(1 - \varepsilon(k^*) \right) \right] ,$$

equivalent to:

$$x^* = \frac{f(k^*) - \delta k^*}{p_X + \frac{\alpha}{1-\alpha} \left(p_X + w^* \right) \left(1 - \varepsilon(k^*) \right)} = \frac{f(k^*) - \delta k^*}{p_X + p_C \frac{c^*}{x^*}} . \tag{43}$$

Furthermore, c^* follows from substituting x^* in the optimality condition:

$$c^* = \frac{f(k^*) - \delta k^* - p_X x^*}{p_C} . \tag{44}$$

7.10 Change of c^* with respect to k^*

The ratio of first order conditions (30) by (31) yields:

$$c^* = \alpha/(1-\alpha) \left(\hat{p}_X^* / p_C \right) \left(1 - \varepsilon(k^*) \right) x^*$$

Recalling that $\hat{p}_X^* = p_X + w^*$ and that w^* also depends on k^*, we derive c^* with respect to k^* and obtain:

$$\frac{dc^*}{dk^*} = \alpha/(1-\alpha) \left[\frac{dw^*/dk^*}{p_C} \left(1 - \varepsilon(k^*) \right) x^* - \frac{p_X + w}{p_C} \frac{d\varepsilon(k^*)}{dk^*} x^* + \frac{p_X + w}{p_C} \left(1 - \varepsilon(k^*) \right) \frac{dx^*}{dk^*} \right]$$

Dividing $\frac{dc^*}{dk^*}$ by $\frac{c^*}{k^*}$, and simplifying, we obtain the elasticity of $c^*$with respect to k^*:

$$\frac{dc^*/c^*}{dk^*/k^*} = \quad -k^* \left[\frac{d\varepsilon(k^*)/dk^*}{(1-\varepsilon(k^*))} - \Delta\left(k^*\right) \frac{dw^*/dk^*}{w^*} - \frac{dx^*/dk^*}{x^*} \right] , \tag{45}$$

As a consequence, the difference between the elasticity of $c^*$with respect to k^* and the elasticity of $x^*$with respect to k^* is:

$$\frac{dc^*/c^*}{dk^*/k^*} - \frac{dx^*/dx^*}{dk^*/k^*} = \quad \left[\Delta\left(k^*\right) \frac{dw^*/w^*}{dk^*/k^*} - \frac{d\varepsilon(k^*)/dk^*}{(1-\varepsilon(k^*))/k^*} \right] , \tag{46}$$

which yields:

$$\frac{dc^*}{c^*} - \frac{dx^*}{x^*} = \left[\underbrace{\Delta\left(k^*\right)\frac{dw^*}{w^*}}_{ROC^*} - \underbrace{\frac{d\varepsilon(k^*)}{(1-\varepsilon(k^*))}}_{DPE^*} \right], \tag{47}$$

Using the functional forms for utility and peer effects, we get:

$$ROC^* = \frac{\eta(1-\eta)k^{*\eta-1}}{(1-\eta)k^{*\eta} + p_X},$$

$$DPE^* = \frac{d\varepsilon(k^*)}{(1-\varepsilon(k^*))} = \kappa\,.$$

which produces equation (28).

7.11 Proof of Proposition 3

The sign of the difference $ROC^* - DPE^*$ is determined by :

$$\frac{\frac{dc^*}{c^*} - \frac{dx^*}{x^*}}{dk^*} = \frac{\underbrace{\frac{\eta(1-\eta)k^{*\eta-1}}{(1-\eta)k^{*\eta} + p_X}}_{ROC^*} - \underbrace{\kappa}_{DPE^*}}{dk^*}, \tag{48}$$

The proof is similar to the proof for Proposition 2. In the presence of DPE*, the sign of this expression is ambiguous, as both terms DPE* and ROC* are positive. However, while coefficient κ, related to the term DPE*, is constant, the term related to ROC* changes as k^* increases. Noticing that $\frac{\eta(1-\eta)k^{*\eta-1}}{(1-\eta)k^{*\eta}+p_X} = \frac{\eta}{k^*+\frac{p_X}{(1-\eta)}k^{*1-\eta}}$We have $\lim_{k\to 0}\left[\frac{\eta}{k^*+\frac{p_X}{(1-\eta)}k^{*1-\eta}}\right] = \infty$, and $\lim_{k\to\infty}\left[\frac{\eta}{k^*+\frac{p_X}{(1-\eta)}k^{*1-\eta}}\right] = 0$. That is, ROC* approaches infinity for a low level of k^*, and it approaches zero for a high level of k^*. Moreover, ROC* is monotonously decreasing as k^* increases. As a consequence, given $\kappa > 0$, the sign of $ROC^* - DPE^*$ is positive for low k^* and negative for high k^*.■

7.12 Proof of Proposition 4

We express steady state weight as:

$$\mathrm{w}^* = \left(\frac{\lambda_C c(x^*, k^*)/x^*}{z\left(k^*\right)}\right),$$

where $z\left(k^*\right) = \lambda_S \bar{s}\left(x^*\right)/x^* + \lambda_X + \lambda_N/x^*$ represents total calorie expenditure divided by exercise expenditure. Comparing body weight for different wealth levels is obtained by totally deriving body weight with respect to k^*, which yields:

$$\frac{d\mathrm{w}^*}{dk^*} = \frac{\lambda_C c^*/x^*}{z^*}\left[\frac{\frac{d(c^*/x^*)}{c^*/x^*} - \frac{dz^*}{z^*}}{dk^*}\right] \tag{49}$$

First, we consider the sign of $\frac{d(c^*/x^*)}{c^*/x^*}$. Based on the proof for Proposition 3:

$$\frac{d(c^*/x^*)}{c^*/x^*} = \frac{dc^*}{c^*} - \frac{dx^*}{x^*} = \left[\underbrace{\Delta\left(k^*\right)\frac{dw^*}{w^*}}_{ROC^*} - \underbrace{\frac{d\varepsilon(k^*)}{(1-\varepsilon(k^*))}}_{DPE^*}\right], \tag{50}$$

We know from Proposition 3 that this term is negative for high values of k^* and converges towards $-\kappa$.

Second, we consider the impact of dk^* on $\frac{dz^*}{z^*}$:

$$\frac{dz^*}{dk^*}/z^* = \frac{\lambda_S \frac{d[\bar{s}(x^*)/x^*]}{dx^*}\frac{dx^*}{dk^*} - \frac{\lambda_N}{x^*}\frac{dx^*/dk^*}{x^*}}{\lambda_S \bar{s}\left(x^*\right)/x^* + \lambda_X + \lambda_N/x^*}$$

We examine the second term of the numerator ($\frac{\lambda_N}{x^*}\frac{dx^*/dk^*}{x^*}$) that denotes the change in exercise that goes with a higher steady state capital stock:

$$\frac{dx^*}{x^*}/dk^* = \frac{1}{p_X + \frac{\alpha}{1-\alpha}\left(1-\varepsilon\left(k^*\right)\right)}\left\{\underbrace{\frac{d\left(f\left(k^*\right)-\delta k^*\right)}{\left(f\left(k^*\right)-\delta k^*\right)}}_{IE^*} + \frac{\alpha}{1-\alpha}\frac{w^*}{\Delta^*}\left(1-\varepsilon\left(k^*\right)\right)\left[\underbrace{\frac{d\varepsilon(k^*)}{(1-\varepsilon(k^*))}}_{DPE^*} - \underbrace{\Delta^*\frac{dw^*}{w^*}}_{ROC^*}\right]\right\}/dk^*$$

This expression indicates that exercise expenditure increases (decrease) when the income effect (IE^*) and the DPE^* are large (small) compared to ROC^*. When k^* is high, we know from proposition that $ROC^* - DPE^*$ is positive and IE^* is positive. Therefore $\frac{dx^*}{x^*}/dk^* > 0$ when k^* is high. We examine the first term of the numerator ($\frac{d[\bar{s}(x^*)/x^*]}{dx^*}$). Based on the definition of $\bar{S}$, we obtain:

$$\bar{s}^* = \frac{1}{N} - 1 - \frac{X^*}{N} = \frac{1}{N} - 1 - x^*$$

Because N is endogenous, we need to make a reasonable assumption: we consider an increase in x^*, representing an increase in X^* given N, or assume that it is not offset by a decrease in N. In that scenario, an increase in x^* produces a decrease in $\bar{s}^*$. In other words, an increase in per worker exercise leads to a decrease in per worker sedentary leisure. Therefore $\frac{d[\bar{s}(x^*)/x^*]}{dx^*} < 0$. As a consequence, since for high values of k^* , x^* increases, and $\frac{dz^*}{dk^*}/z^* < 0$. In other words, the ratio of total calorie expenditure over exercise decreases.

Based on (49), for high values of k^*, $\frac{d\mathrm{w}^*}{dk^*} < 0$ if:

$$\underbrace{\frac{d\left(c^*/x^*\right)}{c^*/x^*}}_{(-)\to-\kappa} < \underbrace{\frac{dz^*}{z^*}}_{(-)} \to \kappa > \underbrace{-\frac{dz^*}{z^*}}_{(+)}.\blacksquare$$

7.13 Formulation of the problem with calorie consciousness

We focus on an individual for whom $W > W^*$. Consistent with Mathieu-Bolh and Wendner (2020), the current-value Hamiltonian becomes:

$$\mathcal{H} = U(C, \hat{X}, W) + \mu \left[rK + w\bar{L} - \hat{p}_X \varepsilon \left(\bar{k}\right) \bar{X} - p_C C - \hat{p}_X \hat{X} \right] - \xi \left[\lambda_C C - \Omega\left(\hat{X}\right) \right],$$

where $\xi > 0$ is the shadow value of weight gain expressed in utility units and: $\Omega\left(\hat{X}\right) = \frac{\left(\lambda_S \bar{S} + \lambda_X X + \lambda_N N\right)}{N\left(\hat{X}\right)} W = \frac{W}{N\left(\hat{X}\right)} \left[\lambda_S \bar{S} + \lambda_X \left(\hat{X} + \varepsilon(k) \bar{X} \right) + \lambda_N N\left(\hat{X}\right) \right]$, and $N\left(\hat{X}\right) = 1 - \bar{S} - \hat{X} - \varepsilon(k) \bar{X}$. An interior solution satisfies:

$$\frac{\partial \mathcal{H}}{\partial C} = U_C - \mu p_C - \xi \lambda_C = 0, \tag{51}$$

$$\frac{\partial \mathcal{H}}{\partial \hat{X}} = U_{\hat{X}} - \mu \hat{p}_X + \xi \underbrace{\left[\frac{W}{N\left(\hat{X}\right)} (\lambda_X - \lambda_N) - \frac{\Omega\left(\hat{X}\right)}{N\left(\hat{X}\right)} \right]}_{\equiv \hat{\lambda}_X} = 0, \tag{52}$$

where $\hat{\lambda}_X$ represents calorie expenditure per unit of effective exercise. The canonical equations regarding the state variable K are unchanged (see (32) and (3233)) but we need to add an intertemporal condition and a transversality condition regarding the state variable W :

$$\frac{\partial \mathcal{H}}{\partial W} = U_W + \xi \frac{\Omega\left(\hat{X}\right)}{W} = -\xi \rho + \dot{\xi}. \tag{53}$$

$$\lim_{\tau \to \infty} \xi(\tau) e^{-\rho \tau} W(\tau) = 0, \tag{54}$$

Solving the first-order conditions for μ yields:

$$\mu = \frac{U_C}{p_C} - \xi \frac{\lambda_C}{p_C} = \frac{U_{\hat{X}}}{\hat{p}_X} + \xi \frac{\hat{\lambda}_X}{\hat{p}_X}. \tag{55}$$

It follows that:

$$\frac{U_C}{p_C} - \frac{U_{\hat{X}}}{\hat{p}_X} = \frac{U_C}{\hat{p}_X} \left[\frac{\hat{p}_X}{p_C} - \frac{U_{\hat{X}}}{U_C} \right] = \xi \left(\frac{\hat{\lambda}_X}{\hat{p}_X} + \frac{\lambda_C}{p_C} \right) \geqslant 0. \tag{56}$$

7.14 Proof of Proposition 5

Straightforward from (56). If $\xi = 0$ (individuals are calorie unconscious):

$$\frac{U_{\hat{X}}}{U_C} = \frac{\hat{p_X}}{p_C}.$$

If $\xi > 0$ (overweight individuals are calorie conscious), then:

$$\frac{U_{\hat{X}}}{U_C} < \frac{\hat{p_X}}{p_C}.$$

As a result:

$$\frac{U_{\hat{X}}}{U_C}|_{\xi>0} < \frac{U_{\hat{X}}}{U_C}|_{\xi=0} \iff \frac{C}{\hat{X}}|_{\xi>0} < \frac{C}{\hat{X}}|_{\xi=0}. \blacksquare$$

7.15 Calibration

First, we set parameters for the Schofield equation. We use data on time use, calories spent exercising, and basal metabolic rate to calibrate the parameters of the Schofield equation.

An individual spends about 2000 hours per year working (40 hours times 50 weeks) out of 8736 total hours in a year (24 hours time 7 days times 52 weeks). The time that is not spent working represents 6736 hours of leisure time (8736 - 2000 = 6736) and is split between sedentary leisure and exercise. With exercise time representing only 122 hours (20 minutes times 365 days divided by 60), sedentary leisure represents 6614 hours (6736 -122 = 6614). As a result, sedentary leisure represents a fraction equal to $\bar{S} = 6614/8736 = 75.7\%$ of total time, and time that is not spent on sedentary leisure represents a fraction of $\bar{L} = 1 - 0.757 = 24.3\%$ of total time. This time is split between exercise, which represents a fraction equal to 122/8736=1.4% of total time, and work, which represents a fraction equal to 2000 / 8736 = 22.9% of total time. The average of men and women average weight in the US is 185 pounds. On average, an individual at rest spends $\lambda_S \bar{S} W = 1577.5$ calories per day. As a result, $\lambda_S = 1577.5/(0.757 * 185) = 11.26$.

Based on the yearly American time use survey by the Bureau of Labor Statistics (BLS), time spent "participating in sports, exercise and recreation", measured since 2003, represents 0.33 hours (20 minutes) a day for the average individual. How many calories do those activities burn? The 2008 BLS Spotlight on Statistics indicates that the three most popular types of exercise are walking, weightlifting, and using cardiovascular equipment (see Figure A2 in the appendix). For a 185 pound individual, we estimate that these activities respectively burn 2.0, 1.4 and 4.7 calories per pound per hour. The calories burnt are taken from the chart provided by Harvard Medical School and activities specifically correspond to walking 4 miles per hour, general weight lifting, and high impact step (or vigorous rowing). We estimate that calories burnt by an individual splitting their exercise time among those three activities, weighted by their popularity, equals 2.5 calories per pound per hour. The details of our calculation are provided in Table A1 in the appendix. Thus, an average individual of 185 pounds, spends $2.5 * 185 = 462.5$ calories per hour. Since individuals exercise 20 minutes a day, they spend $\lambda_X X W$ =154 calories per day. As a result, $\lambda_X = 154/(0.014 * 185) = 59.5$.

Based on the U.S. Department of Health and Human Services (HHS), we use the average of daily caloric expenditure of men and women, which equals ((1600+2400)/2+(2000+3000)/2)/2=2250. With 1577.5 calories spent in sedentary leisure and 154 calories spent exercising, calories spent at work are $\lambda_N N W = 2250 - 1577.5 - 154 = 518.5$. As a result, $\lambda_N = 518.5/(0.23 * 185) = 12.2$.

In order to estimate parameter λ_C (energy density of food), we use the Schofield equation, written for a stationary body weight: $\lambda_C = \frac{(\lambda_S \bar{S} + \lambda_X X + \lambda_N N) W/N}{C} = \frac{2250}{4} = 562.5$ per unit of food expenditure per day. As explained above, the numerator represents total calorie expenditure per day. The denominator represents the quantity of food consumed per day, which is between 3 and 5 pounds. We take 4 pounds for the baseline calibration. As a result, parameter λ_C represents energy intake per unit of food expenditure per day. Note that there is no distinction between men and women or individuals of different ages within households in the per quintile food consumption data.

We need a consistent estimate for food and exercise, so we use cost per day. To estimate the price of exercise, we use the work by Valero-Elizondo (2016), who estimate the marginal benefit of exercising (which, in equilibrium, equals the marginal cost) equal to \$2500 per year. We divide it by by 365 days and by the time a person spends exercising daily to obtain p_X, the price per day. Note that the marginal benefit (or cost) of exercising is high as it represents more than the sole expenditure on exercise related activities or goods in that case. It also encompasses additional benefits in the form of savings on health care expenditure due to better health outcomes. So it overstates the direct cost of goods and services connected to calorie expenditure.

The average amount spent on food since 2003 is $2,251 per person year. We obtain this number as follows. Based on the Consumer Expenditure Survey, aggregate food consumption expenditure per year equals 776,647 millions of dollars. The share of aggregate food expenditure coming from middle income households is 17.8%. The average number of consumer units in the middle income category is 24,560 thousands and the number of person per consumer unit is 2.5. As a result, 776,647,000,000 * 17.8% / 24,560,000 / 2.5 = $2,251 per year per person. We divide this number by 365 days and by the quantity of food a person consumes in a day (4 pounds) to obtain p_C, the price per pounds.

The model is simulated using a production function with a unit elasticity of substitution between consumption and effective exercise ($\zeta = 0$) and a unit intertemporal elasticity of substitution ($\gamma = 1$). We estimate the remaining yearly parameters. They are consistent with the standard range of parameters of theoretical growth models (cf. Turnovsky, 2000; Barro and Sala-i-Martin, 2003) and are adjusted to reproduce some essential features of the US economy. We set the production elasticity of capital η , the rate of depreciation δ , and the rate of time preference ρ to obtain a capital output ratio of 3 (e.g. Burda and Wyplosz, 2017, p.64).

Parameter α, which represent the taste for consumption relative to leisure, and parameter κ, which represent the exogenous component of the degree of peer influence modify steady state peer effects, consumption, calorie expenditure and body weight. However, neither are directly observable. We set those parameters to reflect the following empirical observations. Our calibration generates a degree of peer influence close to 0.4, which is consistent with experimental estimates,[12] and a ratio of exercise related expenditure over food expenditure close to one.

Additionally, the food consumption-income ratio is 10% in the USA and total consumption in output is about 65%. Because our model has only one good, which is food consumption, if we set parameters to reproduce a consumption output ratio of 10 percent, it would mean that most resources are allocated to investment. The economy and food consumption would grow too fast compared to reality. At the same time, if we set parameters to reproduce a consumption output ratio of 65 percent, food consumption and its effect on body weight would largely be overstated. With our parameters, we obtain a ratio of for food consumption in total output between 10 and 65 percent. Parameters are presented in Table 1. Table 2 shows the fit between actual and simulated steady state economies.

Table 1: Parameters

λ_X	λ_N	λ_S	λ_C	$\bar{S}$	p_X	p_C	ρ	δ	η	α	κ	ζ	γ
59.5	12.2	11.26	562.5	0.757	20.76	1.54	0.05	0.05	0.3	0.6	0.1	0	1

[12]Quasi-experimental research provides estimates in the 0.2–0.6 range (see, e.g., Johansson-Stenman et al., 2002; Clark and Senik, 2010; Carlsson et al., 2007; and the overview by Wendner and Goulder, 2008).

Table 2: Actual and simulated economies				
	k/y	$(\hat{p_X}\ X)/(p_C\ C)$	DOP	C/Y
Actual US economy	3	1.1	0.4	between 0.10 and 0.65
Simulated US economy	3	1	0.4	0.28

7.16 Sensitivity analysis

We simulate the static and dynamic relations between body weight and the stock of capital per unit of labor with the price of consumption expenditure ranging from 0 to 20.76. The results are presented in Figure 2.

When the price of exercise expenditure decreases, the static and dynamic Kuznets curves shifts down. The reason is that a lower price of exercise lowers ROC* thereby encouraging exercise. The increase in calorie expenditure results in lower body weight for all levels of the stock of capital.

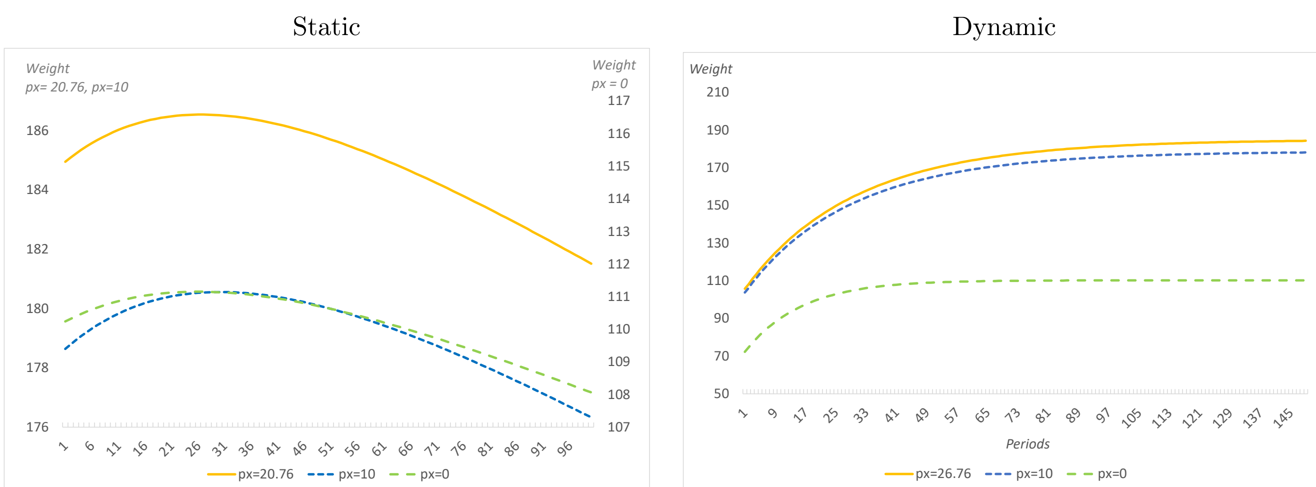

Figure 2: Body weight and capital stock with different consumer prices for exercise

We simulate the static and dynamic relations between body weight and the stock of capital per unit of labor with elasticities of substitution between consumption and effective leisure ranging from 0.66 to 2 (corresponding to ζ ranging from -0.5 to 0.5). The results are presented in Figure 3.

When the elasticity of substitution between food consumption and effective exercise becomes larger than in the baseline scenario and equal to 2, with $\zeta = 0.5$, then, as the stock of capital becomes higher in the steady state, individuals substitute food consumption for exercise more easily than in the baseline with unit elasticity of substitution. As a consequence, the relation between weight and the capital stock is decreasing as the steady-state stock of capital becomes higher. In this case, the relation between steady state weight and the capital stock is not a Kuznets curve. In other words, the DPE* dominates the ROC* for all steady-state levels of capital. In contrast, when the elasticity of substitution between food consumption and effective exercise becomes smaller than in the baseline scenario and equal to 0.66, with $\zeta = -0.5$, individuals substitute food consumption for exercise less easily as the stock of capital becomes higher in the steady state. The relation between steady-state weight and the capital stock is a Kuznets curve. In this case, until a certain level of steady-state stock of capital per unit of labor, the ROC* dominates and weight increases. Beyond this level, the DPE* dominates, and weight decreases as the steady-state stock of capital becomes higher. The static Kuznets curve is also present in the baseline case (solid curve) but less pronounced than for the lower CES with $\zeta = -0.5$.

The dynamic relation between weight and the capital stock does not exhibit a Kuznets curve pattern for a wide range of elasticities of substitution between food consumption and effective exercise. For both the static and dynamic relations, the more food consumption and effective exercise are complements, the more prevalent peer effects, the lower the level of steady state body weight.

To our knowledge, there is no empirical estimate of the elasticity of substitution between food consumption and exercise. If food consumption and exercise are substitutes, we should see a decrease in steady state weight happening much earlier that in our baseline. If we consider that when people exercise, they also eat more, then food consumption and effective exercise may be complements and the relation between steady state weight and stock of capital per unit of labor could exhibit a Kuznets curve. However, the model predicts that with an elasticity of substitution of 0.66, the tipping point of the Kuznets curve would happen at a steady-state stock of capital 67 percent higher and a body weight of 344 pounds, which is a more pessimistic scenario than the baseline scenario.

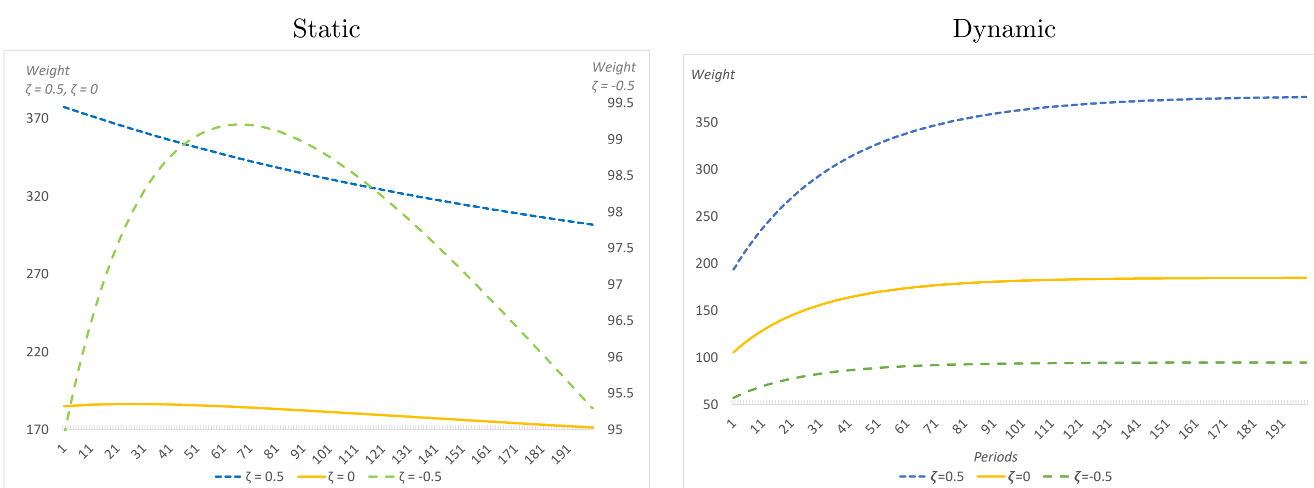

Figure 3: Body weight and capital stock with different elasticities of substitution between food consumption and effective exercise

We simulate the relation between body weight and the stock of capital per unit of labor with intertemporal elasticities of substitution ranging from 0.33 to 1 (corresponding to γ ranging from 3 to one). By definition, the intertemporal elasticity of substitution does not affect the steady state but it modifies the dynamic evolution of weight as the stock of capital builds up. The results are presented in Figure 4.

When the intertemporal elasticity of substitution becomes smaller, from 1 to 0.33 (as γ goes from 1 to 3), the dynamic relation between weight and the stock of capital per unit of labor becomes flatter. As γ increases, the effect of the ROC on the difference between the growth rate of exercise and the growth rate of food consumption, $\frac{\dot{x}}{x} - \frac{\dot{c}}{c}$, becomes smaller, and the effect of the DPE becomes dominant, explaining that the relation between obesity and capital becomes less and less positive. As the DPE become dominant, individuals postpone net calorie intake to the future, which flattens the evolution of body weight.

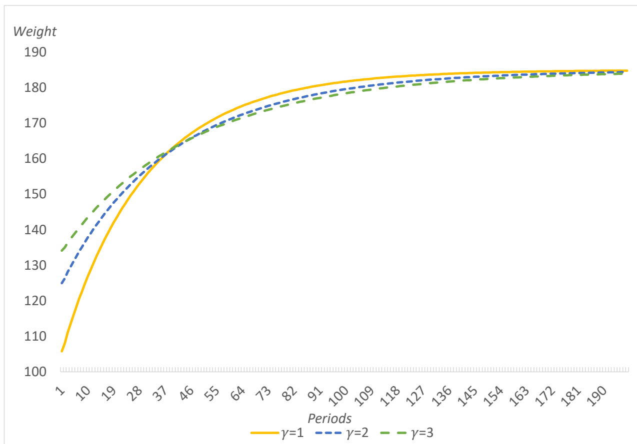

Figure 4: Dynamic of body weight with different intertemporal elasticities of substitution

While in the baseline scenario, the Kuznets curve is generated for low values of κ matching empirical estimates of peer effects, we further explore the role of a higher degree of peer influence in generating a dynamic Kuznets curve and present it in Figure 5. We simulate the evolution of body weight towards its steady state as the stock of capital increases over time for parameter values of κ ranging from 0.78 to 0.82. In that range of values for κ, there are very large differences in the level of body weight: the higher κ, the lower the body weight. The magnitude of those differences is too large to put the results on the same graph. For that reason, instead of presenting the level of body weight, in Figure 5, we present the percentage change in body weight with respect to its steady state value as the stock of capital increases. With high values of κ, we obtain obesity Kuznets curves: Body weight starts below the steady state value and the percentage change with respect to the steady state becomes less negative, which means that body weight increases toward its steady state value. After a number of periods, body weight overshoots its steady state value, and then decreases to its steady state value. For high values of κ, a dynamic Kuznets curve regularly occurs (and is not sensitive with respect to the specific value of κ, as was the case for the lower values of κ discussed in relation to the baseline case).

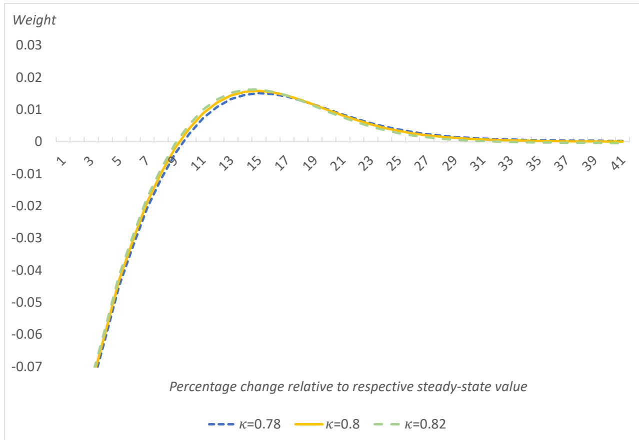

Figure 5: Dynamic of body weight gain with high degrees of peer influence

8 Figures and tables

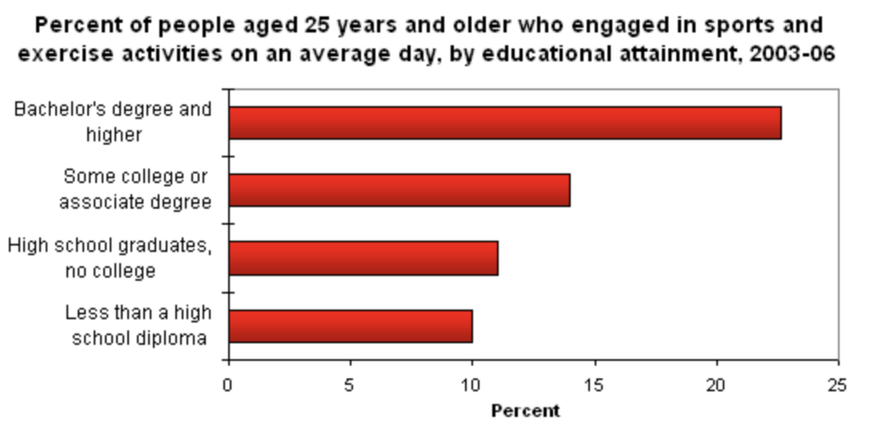

Figure A1: Engagement in sports and educational attainment (Source: American time use survey, 2008)

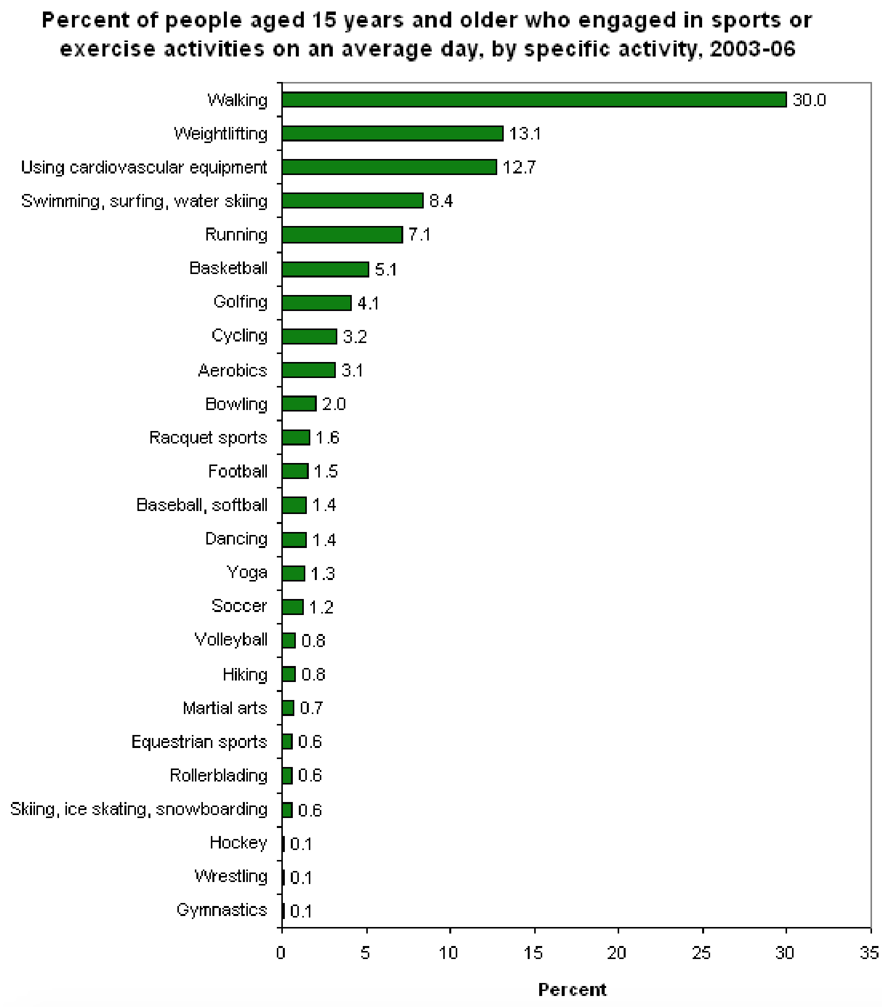

Figure A2: Engagement in sports per type of exercise (Source: American time use survey, 2008)

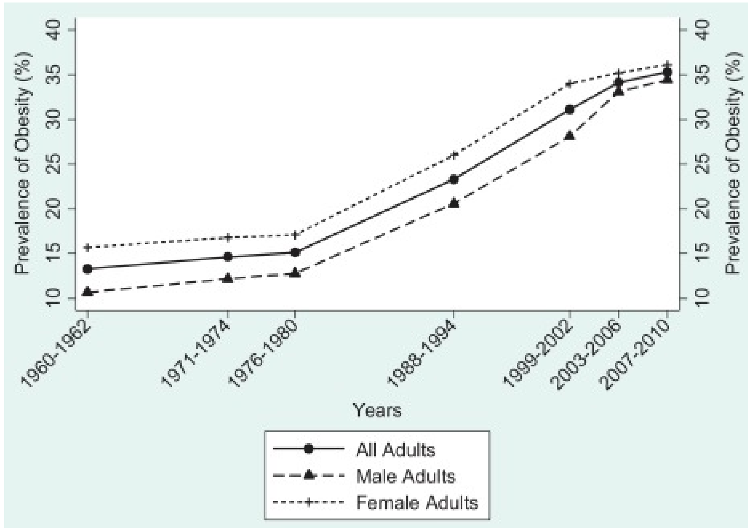

Figure A3: Obesity prevalence over time in the USA (Source: Cawley, 2014)

Table A1: calorie spent per activity

Activity	Percentage of total time	Calorie expenditure per pound per hour
walking	=30/(30+13.1+12.7)=0.54	378/185=2.0
weight lifting	=13.1/(30+13.1+12.7)=0.23	252/185=1.4
cardio	=12.7/(30+13.1+12.7)=0.23	880/185=4.7
Weighted average		2.5

Sources: 2008 BLS Spotlight on Statistics and Harvard Medical School (https://www.health.harvard.edu/diet-and-weight-loss/calories-burned-in-30-minutes-of-leisure-and-routine-activities).