OBESITY AS A SOCIAL EQUILIBRIUM PHENOMENON

Bryony Reich*
University College London
Jörgen W. Weibull
Stockholm School of Economics and *Institute for Advanced Study in Toulouse*

October 4, 2012.

Abstract. We develop a mathematical model of obesity in which individuals value consumption but also have a concern for their body weight, a concern that may be influenced by peers and that may be hampered by a lack of self-control. Our model is thus focused on the interplay between economic, social and psychological factors. It is general but yet tractable enough to permit analysis of a range of factors that have been put forward as relevant to obesity. The model sheds light on stylized facts about the obesity epidemic of the last thirty years and can be used to numerically simulate policy effects and as a workhorse in theoretical and empirical research of obesity.

Keywords: Obesity, fitness, peer effects, social norms, equilibrium, policy.

1. Introduction

While past increases in population weight were health-improving, the widespread increase in weight in recent decades has taken many above medically recommended weight levels (Fogul 1994). Obesity is today prevalent in many countries.[1][2] Despite being associated with increased rates of death from cardiovascular disease, diabetes, stroke, specific cancers and all-cause mortality, obesity rates continue to rise.[3] This rise in BMI and obesity levels of recent decades exhibits two features that have been much commented on. One, the

*We thank the Knut and Alice Wallenberg Research Foundation for financial support and Kristaps Dzonsons for excellent computer simulation work. We thank Mary Burke, Sanjeev Goyal, Frank Heiland, Andrew Oswald and Tomas Philipson for valuable comments.

[1] BMI is defined as body weight, measured in kilograms, divided by the square of height, measured in meters. Obesity is defined as a BMI of 30 or over, while a BMI between 25 and 30 is classed as overweight, and a BMI at 18.5 or below is underweight.

[2] Flegal et al. (2010)

[3] Prospective Studies Collaboration (2009); Berrington et al. (2010)

evolution of the obesity epidemic itself: obesity levels remained relatively flat between 1960 and 1980 and then rocketed between 1980 and 2000. Two, in developed countries, obesity occurs disproportionately among the poorer and less educated. Overweight and obesity constitute not only health risks to individuals, as described above, but impact societies as a whole through the effect on health care systems, lost work days, and productivity.[4] Each of these aspects is important in itself and makes the empirical and theoretical study of individual choice and behavior with regard to body-weight an important one. A recent article in the Lancet (Swinburn et al. (2011)) suggests 'the challenge is to reduce the complexity of obesity enough so that it can be understood by researchers, policy makers, and the public without becoming overly simplistic'. We here take on this challenge.

We present a theoretical framework within which obesity arises as a socio-economic equilibrium phenomenon. Equilibrium always exist (under standard regularity assumptions), but there may be more than one equilibrium at given prices and incomes. Our aim is to provide a family of operational parametric models that can be used as workhorses for researchers who study obesity, theoretically or empirically, models that are transparent, easy to use and yet rich enough to capture key phenomena surrounding obesity. The framework we propose is a slight extension of the standard microeconomic model of the consumer. The additional elements are (1) a metabolism function that determines body weight from the individual's consumption pattern (including food intake and exercise), (2) an ideal body-weight and desire to stay at or near that ideal, (3) a potential lack of self-control in consumption concerning the effects on body weight from consumption, and (4) potential peer effects on body-weight ideals and deviations from these. We imagine a finite population of individuals who face the same market prices but who may differ in income and preferences, and also in the four mentioned dimensions. In particular, some may have a more efficient metabolism, a lower ideal body-weight, more self-control and be more sensitive to peers' fitness than others, etc. Individuals are tied together by peer effects, which are channeled through some pre-existing social network, and where one's peers fitness may affect one's feelings about own fitness. We know of no other theoretical framework that encompass all these aspects.

Our focus is thus on the consumption side of the matter, rather than on production and technological change. This is not to deny the importance of

[4]See Finkelstein et al. (2005) for a discussion and references on the annual healthcare costs and predicted lifetime healthcare costs of obesity, as well as costs due to lost productivity.

technological change for the obesity epidemic. Since the 1960's, significant technological development has taken place in food processing. This change has had a strong influence on consumption patterns, in particular cooking and eating habits. However, this channel, from technological change through market prices to obesity, has been analyzed before, see Culter et al. (2003), Lakdawalla et al. (2005) and Lakdawalla and Philipson (2009). Arguably, there is now more need to deepen our understanding of the consumption side of the matter.

Why is the framework we present here a good way to model the determinants of body weight? The basis of the framework holds that an individual cares both about his or her consumption and also about his or her physical fitness. In the present context, physical fitness is represented by how close an individual is to his or her healthy or ideal weight (later on we indicate how this can be generalized to include a concern for fitness rank). Indeed, this is how health economists have modelled behavior at least since Grossman (1972): an individual decision-maker balances the trade-off between consumption and investment in health. We here look in depth at this trade-off when it comes to body weight and obesity. An analysis of the determinants of body weight has, of course, the added feature that food consumption increases weight and so it is not only the case that spending on consumption crowds out investment in health (for budget reasons), but consumption can have a *direct* effect on health. In previous work on obesity, Lakdawalla, Philipson and Bhattacharya (2005) and Lakdawalla and Philipson (2009) examine a dynamic three-goods model where individuals care about food, other consumption, and body weight.[5] They focus on incorporating this model with the supply side (changing prices and technology) and leave room for further development of the consumption side, which we take up here.

We use the set-up described to think about the context in which individuals' body weight is determined. It is clear that the context is not the same for the rich and poor of this world. An individual with high income facing low food prices has the opportunity to consume a bundle of goods that results in weight above his or her ideal. This individual thus faces a decision of how much to reduce, or alter the composition of food consumption in order to avoid being over-weight. An individual at the other end of the spectrum, facing high food prices and having a very low income, may not have the opportunity to consume so much food that this results in being over-weight. This individual instead faces

[5] See also Cutler, Glaeser and Shaprio (2003), Burke and Heiland (2007), Dragone (2009) and Dragone and Savorelli (2012).

a decision of how much to substitute towards food and away from other goods in order to improve his or her physical fitness by way of increased body weight. We identify these two situations in our formal model and refer to them respectively as living in, or not in, *nutritional affluence*. While the model encompasses both situations, it is clear that the results will differ between the two situations and this distinction is vital to any analysis.

We show that a larger budget set endogenously alters the trade-off between consumption and physical fitness, increasing the importance of fitness relative to consumption. Thus richer individuals, with the same preferences and self-control as poor individuals, behave as if they placed more 'importance' on physical fitness and as a result may ultimately be more fit. This qualitative result is transferable to other 'bad behaviors' such as smoking. Health-economics is concerned with why poorer individuals might engage more in 'bad' health behaviors, such as over-consumption of unhealthy foods and smoking, despite these habits being both economically costly and costly to health.[6][7] We are not aware of another model which shows that this result will arise (and why) simply from the individual's trade off between consumption and health.

Outside the literature on health behavior, Banerjee and Mullainathan (2010) propose another model of consumption decisions, a model that, like ours, explains why the behavior of the poor may be seemingly more myopic, without the poor necessarily having different time preferences than the rich. In their model, people move consumption closer to the present to avoid their future selves wasting money on "temptation" goods. An increase in income — and thus increased consumption — results in a larger decrease in the marginal utility of temptation goods than of non-temptation goods, and so richer individuals end up spending a smaller fraction of their last dollar on the former.

Our model also incorporates the possibility of social influences. More exactly, we allow an individual's perception and valuation of his or her own physical fitness, both in terms of fitness ideals and in terms of discomfort from deviating from such ideals, to be more or less influenced by the fitness of peers. There is a growing literature examining the possibility of peer effects in weight gain and

[6] This is not to deny the possibility that it is not only real income that matters. There could of course be an underlying factor that results both in low income/education and obesity. One such factor is present in our model: self-control. Individuals with low self-control may end up with lower education, income and obesity. See Heckman and Kautz (2012) for results pointing to this possibility.

[7] Also to explain educational differences in BMI, Burke and Heiland (2006) assume there to be a higher cost of non-conformity to the group weight norm on those with a higher education status.

how, when peer effects are present, the same reduction in the price of food can result in a greater increase in BMI as a result of the social multiplier.[8] Burke and Heiland (2007) calibrate a model of peer effects with falling food prices and show that including peer effects allows them to better match the BMI changes that occurred from just before 1980 up to 2000. To fully understand the current obesity epidemic, one would have to explain why the multiplier effect seems to have kicked in only around 1980 and not when food prices fell in the 1960s and 1970s. Our theoretical analysis provides such an explanation: with a gradual fall in the price of food, peer effects may well initially produce relatively small increases in BMI, followed by a sharp increase. Further, substantial peer effects will only kick in when food prices are low enough. This is again due to the individual's trade-off between consumption and physical fitness. This appears to be a novel explanation of why we might see a sharp rise in BMI or obesity levels when prices are low enough and deepens our understanding of how peer effects would work as regards weight gain and obesity.

While our model allows for the possibility that some or all individuals may not have full self-control when it comes to the effects of consumption (say food and exercise) on their fitness, this feature is not critical to any of the results we find. Indeed, in the parametric specification that we mostly focus on, a lack of self-control has exactly the same effect as a lack of sensitivity to one's fitness (all results depend only on the product of these two parameters). Thus while we do not rule out the possibility of temptation and a lack of self-control, we subscribe to the view of Lakdawalla et al. (2005) that 'a neoclassical interpretation of weight growth that relies on changing incentives does surprisingly well in explaining the observed trends, without resorting to psychological, genetic, or addictive models.'

The rest of the paper is organized as follows. The general model is presented in Section 2. Section 3 introduces a flexible parametric form of the model and establishes the existence of equilibrium. We then focus on the special case of only one weight-enhancing good and examine the comparative-statics properties of the model; that is, how an individual's BMI is affected by prices, income, preferences, physiology and self-control. Section 4 examines empirical evidence relating to the comparative-statics properties discussed. Section 5 builds on the findings in Section 3 and 4 to investigate the impact of fat taxes. Section 6 studies peer effects and the possibility of multiple equilibria. Section

[8]See Cohen-Cole and Fletcher (2008) for a discussion of the difficulties of empirically identifying peer effects in health outcomes.

7 discusses the obesity epidemic in the light of our model. Section 8 concludes, and mathematical proofs are given in an Appendix at the end of the paper.

2. A THEORETICAL FRAMEWORK

Consider a society consisting of n individuals $i \in I = \{1, ..., n\}$ and m goods $k \in K = \{1, ...m\}$. Each individual i chooses a vector of goods, or a *consumption pattern*, $x_i = (x_{i1,} x_{i2}, \ldots, x_{im})$, from her budget set

$$B(p, Y_i) = \left\{ x_i \in \mathbb{R}^m_+ : \sum_{k=1}^{m} p_k x_{ik} \leq Y_i \right\} \tag{1}$$

where $p = (p_1, ..., p_m)$ is the price vector and Y_i is i's disposable income. In this study, we will treat all prices and incomes as positive, and focus on individuals' consumption patterns at given prices and incomes. An individual's BMI, w_i, is determined by her consumption pattern and her metabolism, $w_i = \phi_i(x_i)$. We will call ϕ_i i's *metabolism function*, and assume ϕ_i to be exogenously given and continuous. The vector $\mathbf{x} = (x_1, ..., x_n) \in \mathbb{R}^{mn}_+$ will be called the *population consumption-profile* and the accompanying vector $\mathbf{w} = (w_1, ..., w_n) \in \mathbb{R}^n_+$, where $w_j = \phi_j(x_j)$ for each individual j, the *population BMI-profile.*

The only way in which the individual can influence her BMI — given her metabolism function — is by changing her consumption pattern. When choosing her consumption pattern, the individual is concerned both with the enjoyments associated with consumption *per se* and with the consequences for her BMI. Each individual i thus has two components of utility. One component, denoted $u_i(x_i)$, is the subutility from (own) consumption, to be called the *subutility from consumption.* The second component of utility is the individual's satisfaction (or dissatisfaction) with own BMI.[9] We allow this utility component, denoted $v_i(\mathbf{w})$, to depend both on her own and others' BMI. We call $v_i(\mathbf{w})$ the *subutility from fitness.*[10]

We assume that both u_i and v_i are continuous, that u_i is strictly quasi-concave and strictly increasing in all its arguments, and that, for any given BMI-profile $\mathbf{w}$, the fitness subutility is strictly quasi-concave in i's own BMI,

[9] There are a number of reasons why individuals care about their weight. Overweight and/or underweight individuals face physical costs (Wang et al., 2011) including health costs and inability to perform tasks, as well as social and economic costs including disadvantages in job markets (Cawley, 2004) and marriage markets (Carmalt et al., 2008).

[10] So far, we have not departed from standard microeconomic theory, which permits a consumer's utility to depend more or less arbitrarily on the consumption pattern; we have only given this dependence an explicit structure that will facilitate the subsequent analysis.

w_i, with a unique maximum point, to be called individual i's *ideal BMI* — at the given BMI-values for all others.

By contrast, the individual's actual or *equilibrium* consumption pattern, x_i, maximizes a weighted sum of consumption and fitness utility,

$$U_i(\mathbf{x}) = \ln u_i(x_i) + \beta_i \cdot \ln v_i(\mathbf{w})$$

where $\beta_i \in (0,1]$ is the weight attached to fitness, and $w_j = \phi_j(x_j)$ for $j = 1,..,n$ (hence each individual's total utility is a function of the whole population consumption profile). We think it is realistic to allow for departure from the standard rationality assumptions of economics when modelling individual decision-making in this context. In particular, the parameter β_i can be viewed as a discounting, at the moment of the actual consumption choice, of the importance of fitness (which in practice comes only with a delay) in comparison with the (instantaneous) gratification from consumption. We scale the subutility functions in such a way that an individual with full self-control would give equal weight to both subutility components ($\beta_i = 1$). Hence, a value $\beta_i < 1$ will be interpreted as *imperfect self-control.*[11] While we here use the term 'self-control,' this potential discrepancy could be the effect of other causes discussed in the health literature such as poor cognitive abilities, see Goldman and Smith (2002), Auld and Sidhu (2005) and Cutler and Lleras-Muney (2010).

In order to allow for endogenous peer effects, we view the n individuals as 'players' engaged in a simultaneous-move 'game', in which each player i chooses a 'strategy' $x_i \in B(p, Y_i)$ that maximizes her 'payoff' $U_i(\mathbf{x})$ (hence allowing for imperfect self-control). A pure-strategy *Nash equilibrium* is thus a population consumption profile $\mathbf{x}^* \in \mathbb{R}_+^{mn}$ such that, for all individuals $i \in I$,

$$x_i^* \in \arg\max_{x_i \in B(p,Y_i)} U_i(x_i, \mathbf{x}_{-i}^*) \tag{2}$$

where $(x_i, \mathbf{x}_{-i}^*) \in \mathbb{R}_+^{mn}$ is the consumption profile that results if individual i consumes x_i while all others consume according to the profile $\mathbf{x}^*$. We will henceforth refer to pure-strategy Nash equilibria as *population equilibria.* In such a population equilibrium $\mathbf{x}^*$, i's consumption pattern, x_i^*, will be referred

[11] The factor β_i can be interpreted as $e^{-r_i t}$, where r_i is the individual's subjective discount rate and t is the lag between consumption and weight increase. Indeed a recent body of work has focused on modeling the dynamics of weight loss. As a rule of thumb they suggest that a given change of energy intake per day will result in an eventual weight change, however, only half of that eventual weight change will be achieved within a year and 95% in 3 years. See Hall et al. (2011) for a summary piece in the Lancet.

to as her *actual* or *equilibrium consumption,* and we will call $w_i^* = \phi_i(x_i^*)$ her *actual* or *equilibrium BMI.*

Recall that an individual's *ideal BMI* is defined as the unique BMI-level that maximizes her subutility from fitness, $v_i(\mathbf{w})$, given a BMI profile for all others, $\mathbf{w}_{-i} \in \mathbb{R}_+^{n-1}$. We denote i's ideal BMI by $\hat{w}_i(\mathbf{w}_{-i})$. By contrast, an individual's *unconcerned consumption* is the consumption that results if she had no concern at all for fitness and simply maximizes her subutility from consumption. An individual's *unconcerned BMI*, w_i^o, is thus defined by $w_i^o = \phi_i(x_i^o)$ where

$$x_i^o \in \arg\max_{x_i \in B(p,Y_i)} u_i(x_i).$$

The existence and uniqueness of such an *unconcerned consumption pattern*, x_i^o, follows from our assumptions.[12]

Consider an individual i with a concern for her fitness who (a) could afford to consume more than is required for her ideal BMI (which may depend on others' BMI), and (b) would have done so, had she disregarded the fitness consequences of her consumption. Arguably, an overwhelming majority of the current populations of developed countries live in 'nutritional affluence' in this sense. To be more precise, we define this concept as follows:

Definition 1. *Individual i lives in a situation of nutritional affluence if her unconcerned BMI is greater than her ideal BMI.*

(We note that a change in others' BMI levels, *ceteris paribus*, may change an individual's situation towards or away from nutritional affluence.) The actual or equilibrium BMI of an individual who lives in nutritional affluence is, as one would expect, never below her ideal BMI:

Lemma 1. *The equilibrium BMI of any individual who lives in nutritional affluence weakly exceeds her ideal BMI.*

(For a proof, see Appendix.) Although we will here focus on the case of nutritional affluence, the model can equally analyze consumption and BMI decisions made by individuals living in nutritional poverty (below nutritional affluence).[13] We proceed to render the above general model in flexible parametric form.

[12] The continuity of the subutility function in combination with the nonemptiness and compactness of the budget set implies existence. The strict quasi-concavity of the subutility function in combination with the convexity of the budget set implies uniqueness.

[13] We will not, however, examine aneroxia in affluent societies. See Dragone and Savorelli (2012) for an analysis. While this is an important topic, it represents a much smaller proportion of the population in the US relative to those who are overweight or obese.

3. A parametric specification

Following previous literature (Cutler, Glaeser & Shapiro, 2003) we henceforth assume each individual's metabolism function to be affine:

$$w_i = \phi_i(x_i) = \sum_{k=1}^{m} \theta_{ik} x_{ik} - \varepsilon_i \tag{3}$$

where $\theta_{ik} > 0$ when consumption of good k increases BMI (such as food), $\theta_{ik} < 0$ when consumption of good k reduces BMI (such as exercise), and $\theta_{ik} = 0$ when good k has no impact on BMI.

Remark 1. *One may think of the metabolism function as the steady-state BMI, given daily food consumption x_{1i}. To derive the metabolism function consider the dynamic weight equation: $W_t = W_{t-1} - \gamma \cdot BMR + 0.9F_t$, where $\gamma > 0$. Current weight is a function of past weight W_{t-1}, the basal metabolic rate (BMR) which measures the calories expended simply to keep the body functioning at rest, and food intake F_t of which ten percent is lost to the thermic expenditure of consuming food.*[14] *The basal metabolic rate is estimated to be affine in weight, $BMR = a + bW$, with $a > 0$ and $b > 0$ (see Schofield, 1985).*[15] *Substituting this into the dynamic weight equation and rearranging terms to find steady state weight as a function of a constant food intake: $W = (0.9F/\gamma - a)/b$. BMI divides weight in kilograms by the individual's height in meters squared and so the above derivation implies we can write the metabolism function as $w_i = \theta_i x_{1i} - \varepsilon_i$ where $\theta_i > 0$ and $\varepsilon_i > 0$. The parameters θ_i and ε_i incorporate idiosyncratic factors such as height and metabolism. For example, if a represents the idiosyncratic part of the metabolic rate, then this shows up in our metabolism function in the term ε_i where a higher ε_i represents a faster metabolism.*[16]

Second, we assume i's subutility from her own physical fitness to be a bell-shaped function of her BMI, given others' BMI,

$$v_i(\mathbf{w}) = e^{-\sigma_i \cdot (w_i - \mu_i)^2/2} \tag{4}$$

[14] This can also be adapted to include energy expenditure from exercise.

[15] A BMR that is linear in weight is common in predictive work. However, there are some studies that question this relationship in favor of declining marginal effects of bodyweight on basal metabolic rate. See Burke and Heiland (2007) for a discussion.

[16] See Ravussin and Bogardus (1989) for details on idiosyncratic metabolic rates.

where μ_i and σ_i are positive continuous (real-valued) functions of the BMI-profile of others, $\mathbf{w}_{-i}$. With fitness subutility represented in this form, i's ideal BMI is simply μ_i, and σ_i reflects how fast i's satisfaction with own fitness decreases as her actual BMI deviates from her ideal BMI. We thus term σ_i the *fitness sensitivity* parameter (which, like μ_i, is allowed to depend on w_{-i}). For individuals with a BMI close to their ideal, a moderate weight increase initially has little effect on their fitness utility but then picks up as BMI deviates further from the ideal and finally the marginal effect decreases again as BMI deviates very far from ideal.

Remark 2. *We have defined an individual's total utility as the sum of the logarithms of his or her subutility from consumption and from fitness. Given others' BMI values, the logarithm of fitness utility,* $-\sigma_i \cdot (w_i - \mu_i)^2/2$, *is a quadratic "loss function" and hence the marginal effect on total utility of a change in body weight is always increasing as the individual's BMI deviates further from her ideal.*[17]

Thirdly, we assume that consumption utility exhibits *constant elasticity of substitution (CES)*:

$$u_i(x_i) = \left(\sum_{k=1}^{m} \alpha_{ik} x_{ik}^{\rho_i}\right)^{1/\rho_i}$$

for $\rho_i < 1$, and for α_{ik} positive and summing to unity.[18] Each parameter α_{ik} represents the intensity of individual i's desire for consumption good k, and ρ_i represents the degree of substitutability between goods.

Combining the three parametric specifications above, we obtain

$$U_i(\mathbf{x}) = \frac{1}{\rho_i} \ln\left(\sum_{k=1}^{m} \alpha_{ik} x_{ik}^{\rho_i}\right) - \frac{\beta_i \cdot \sigma_i(\mathbf{w}_{-i})}{2} \cdot \left[\sum_{h=1}^{m} \theta_{ih} x_{ih} - \varepsilon_i - \mu_i(\mathbf{w}_{-i})\right]^2 \quad (5)$$

where $w_j = \phi_j(x_j)$ and the functions $\sigma_i : \mathbb{R}^{n-1} \to \mathbb{R}$ and $\mu_i : \mathbb{R}^{n-1} \to \mathbb{R}$ are continuous.

[17] According to professor Stephan Rossner at the Karolinska Institute in Stockholm (oral communication), this agrees with empirical observations. Also Lakdawalla, Philipson and Bhattacharya (2005) use a quadratic loss function.

[18] This is a well-known parametric form in the economics literature. As $\rho_i \to -\infty$ it approaches a Leontief function, for $\rho_i = 0$ it can be idenfied with a Cobb-Douglas function, and as $\rho_i \to 1$ it approaches a linear utility function.

If good k is consumed in a positive amount by individual i, then its marginal utility to individual i is well-defined (holding others' BMI levels fixed):

$$\frac{\partial U_i(\mathbf{x})}{\partial x_{ik}} = \alpha_{ik} x_{ik}^{\rho_i - 1} \cdot \left(\sum_{k=1}^{m} \alpha_{ik} x_{ik}^{\rho_i} \right)^{-1} - \beta_i \sigma_i \theta_i \cdot (w_i - \mu_i) \tag{6}$$

This marginal utility is continuous in x_i and tends to plus infinity as consumption of good k tends to zero. Hence, it is never optimal for a consumer to not consume a good, so $x_{ik} > 0$ for all individuals i and goods k. Under the above parametric specification of our general model, the existence of at least one population equilibrium is established by standard methods:

Proposition 1. *If all individuals have utility functions of the form (5), for $\rho_i < 1$, and with μ_i and σ_i continuous (in others' BMI), then there exists a population equilibrium. Moreover, all population equilibria are interior.*

(For a proof, see Appendix.)

Henceforth we assume μ_i and σ_i are independent of others' fitness and return to the question of peer effects in section 6. We will also hereafter assume that the budget constraint is binding; a sufficient condition for this is that at least one good has a non-positive effect on body weight, $\theta_{ik} \leq 0$ for some k.[19] Demand for good k can be written as a fixed-point equation:

$$x_{ik} = \frac{\left[\alpha_{ik}/P_{ik}(w_i)\right]^{1/(1-\rho_i)}}{\sum_h p_h \left[\alpha_{ih}/P_{ih}(w_i)\right]^{1/(1-\rho_i)}} \cdot Y_i \qquad \forall k \in K \tag{7}$$

where

$$P_{ik}(w_i) = \left[1 + \beta_i \sigma_i \left(\theta_{ik} \frac{Y_i}{p_k} - w_i - \varepsilon_i \right) (w_i - \mu_i) \right] \cdot p_k$$

is a factor that depends on own body weight w_i which in turn depends on the individual's consumption pattern x_i according to (3). The model is solved by simultaneously solving the m equations (7).

In the special case of no concern for fitness, $\sigma_i = 0$, we have $P_{ik}(w_i) \equiv p_k$ and the fixed-point equation (7) produces the familiar solution

$$x_{ik}^{o} = \frac{(\alpha_{ik}/p_k)^{1/(1-\rho_i)}}{\sum_{h=1}^{m} p_h (\alpha_{ih}/p_h)^{1/(1-\rho_i)}} \cdot Y_i \qquad \forall k \in K$$

[19] Let $\lambda_i > 0$ be the Lagrangian associated with individual i's budget constraint. The marginal utility of money, λ_i, is then positive since the consumer always has positive marginal utility with respect to such a good k.

or indeed, when $\sigma_i = 0$ and $\rho_i = 0$, the Cobb-Douglas solution $x^*_{ik} = \alpha_{ik} Y_i / p_k$. When individuals —more realistically— have some fitness concern, $\sigma_i > 0$, the factor $P_{ik}(w_i)$ may differ from the market price, p_k. What then can be said about an individual's equilibrium consumption pattern and body weight? The factor $P_{ik}(w_i)$ also accounts for the individual's metabolism and fitness concern when making his or her consumption decisions. We note that this "fitness-adjusted subjective price" may exceed the market price p_k when θ_{ik} (the effect of good k on BMI) is large relative to other goods, while it may fall short of p_k when θ_{ik} is small.

Remark 3. *Suppose that only two goods have an effect on body weight:* $\theta_{i1} = a_i > 0$, $\theta_{i2} = ... = \theta_{i,m-1} = 0$ *and* $\theta_{im} = -c_i < 0$. *Call good* 1 *"food" and good* m *"gym". Then*

$$P_{ik}(w_i) = p_k \cdot \begin{cases} 1 + \beta_i \sigma_i (a_i Y_i / p_1 - w_i - \varepsilon_i)(w_i - \mu_i) & \text{for } k = 1 \\ 1 - \beta_i \sigma_i (w_i + \varepsilon_i)(w_i - \mu_i) & \text{for } k = 2, .., m-1 \\ 1 - \beta_i \sigma_i (a_i Y_i / p_m + w_i + \varepsilon_i)(w_i - \mu_i) & \text{for } k = m \end{cases}.$$

Consider an individual with body weight above her ideal ($w_i > \mu_i$) *who cares about her body weight* ($\beta_i \sigma_i > 0$). *Her fitness-adjusted subjective price of food,* $P_{i1}(w_i)$, *exceeds its market price,* p_1, *that of gym,* $P_{im}(w_i)$, *falls short of its market price,* p_m. *By assumption, all goods give positive consumption utility,* $\alpha_{ik} > 0$. *Suppose, by contrast, that going to the gym gives zero consumption utility,* $\alpha_{im} = 0$; *its sole purpose being to enhance fitness. Then the individual will go to the gym enough so that the (subjectively discounted) marginal effect on fitness equals the (real) marginal cost of going to the gym:*

$$w_i = \mu_i + \frac{\lambda_i p_m}{\beta_i \sigma_i c_i},$$

where $\lambda_i > 0$ *is the Lagrangian associated with* i*'s budget constraint.*[20] *It follows that the individual will exceed his or her BMI ideal* ($w_i > \mu_i$), *and more so the more expensive the gym is (the larger* p_m *is), but less so the more* i *cares about her fitness (the larger* $\beta_i \sigma_i$ *is) and the more effective the gym is on* i*'s body weight (the larger* c_i *is), and the less so the richer* i *is (the higher* Y_i *is, and hence the lower* λ_i *is, ceteris paribus).*

3.1. The case of two goods. In order to clarify the effect of a concern for fitness, in the simplest possible setting, we here consider, within the parametric

[20]To see this, solve $\partial U_i / \partial x_{i3} = \lambda_i p_3$ for w_i when $\alpha_{i3} = 0$.

specification of the general model, a world with only two goods, where good 1 is weight-enhancing and good 2 has no effect on weight. For concreteness and brevity, we will call good 1 *food*. More precisely: let $k = 2$, $\theta_{i1} > 0$ and $\theta_{i2} = 0$.

In this special case, the utility function of each individual i boils down to

$$U_i(\mathbf{x}) = \frac{1}{\rho_i} \ln(\alpha_{i1} x_{i1}^{\rho_i} + \alpha_{i2} x_{i2}^{\rho_i}) - \frac{\beta_i \sigma_i}{2} (\theta_{i1} x_{i1} - \varepsilon_i - \mu_i)^2$$

Division of the first-order conditions for the two goods and substituting for the budget equation gives the first-order condition in only one variable, the individual's consumption of food:

$$\begin{aligned} & \frac{\alpha_{i1}}{\alpha_{i2}} \left[1 - \beta_i \sigma_i (\theta_{i1} x_{i1} - \varepsilon_i - \mu_i) \theta_{i1} x_{i1}\right] \cdot \left(\frac{Y_i - p_1 x_{i1}}{p_2 x_{i1}}\right)^{1-\rho_i} \\ = \; & \frac{p_1}{p_2} + \beta_i \sigma_i \theta_{i1} (\theta_{i1} x_{i1} - \varepsilon_i - \mu_i) \cdot \frac{Y_i - p_1 x_{i1}}{p_2} \end{aligned} \tag{8}$$

Compare this equation when individual i has a concern for fitness $\sigma_i > 0$, with the case when she has no concern for fitness $\sigma_i = 0$. The unique solution when $\sigma_i = 0$ is x_{i1}^o, the individual's unconcerned consumption of food**,** with accompanying BMI, $w_i^o = \theta_{i1} x_{i1}^o - \varepsilon_i$. Suppose that the individual lives in nutritional affluence, $w_i^o > \mu_i$. If the same individual would have a concern for fitness, but still consume x_{i1}^o, then this would violate the necessary equilibrium condition (8), because then $\beta_i \sigma_i (\theta_{i1} x_{i1}^o - \varepsilon_i - \mu_i) \theta_{i1} x_{i1}^o > 0$ and thus the quantity on the left-hand side of the equation would be smaller, when evaluated at x_{i1}^o and the quantity on the right-hand side would be larger. It is necessary that the new equilibrium consumption of good 1 would be lower, $x_{i1}^* < x_{i1}^o$. Hence, not surprisingly $w_i^* < w_i^o$ when $\sigma_i > 0$. We know from Lemma 1 that equilibrium BMI cannot fall below ideal BMI. In sum:

Proposition 2. *An individual with a concern for fitness, $\sigma_i > 0$, who lives in nutritional affluence ($w_i^o > \mu_i$) will obtain an equilibrium BMI between her ideal and unconcerned BMI levels; $w_i^o > w_i^* \geq \mu_i$.*

Proposition 2 states that, in richer societies, where buying enough food to attain one's ideal BMI is not an issue ($w_i^o > \mu_i$), individuals have BMI above ideal. Nevertheless, consumption of food is below that which they would consume were they not concerned with their fitness.[21]

[21] Analogously, an individual who does not live in affluence ($w_i^o < \mu_i$) has $\beta_i \sigma_i (\theta_{i1} x_{i1}^o - \varepsilon_i - \mu_i) \theta_{i1} x_{i1}^o < 0$ and so by a similar argument will obtain equilibrium BMI below her ideal BMI, μ_i, but above her unconcerned BMI, w_i^o.

Consider an individual who lives in affluence ($w_i^o > \mu_i$). In equilibrium, the right-hand side of equation (8) is then positive, and thus also the left-hand side, implying that the factor in square brackets must be positive. Dividing through with that factor, we obtain

$$\frac{\alpha_{i1}}{\alpha_{i2}} \left(\frac{Y_i - p_1 x_{i1}}{p_2 x_{i1}} \right)^{1-\rho_i} = \frac{p_1}{p_2} + \frac{\beta_i \sigma_i \theta_{i1} (\theta_{i1} x_{i1} - \varepsilon_i - \mu_i) Y_i}{1 - \beta_i \sigma_i \theta_{i1} (\theta_{i1} x_{i1} - \varepsilon_i - \mu_i) x_{i1}} \cdot \frac{1}{p_2} \tag{9}$$

The left-hand side is continuous and strictly decreasing in food consumption, x_{i1}, from plus infinity towards zero as x_{i1} increases from its lowest value, zero, to its highest value. Y_i/p_1. The right-hand side is continuous and increasing in x_{i1}, and is positive when $x_{i1} = Y_i/p_1$. Hence, (9) has a unique solution, x_{i1}^*.

Equation (9) shows how an individual's food consumption is influenced by three economic factors; the price of food, the price of other goods, and income. These three (nominal) factors can be summarized in two: the individual's *real* income, $y_i = Y_i/p_2$, as defined in terms of other goods, and the *relative* price of food, $p = p_1/p_2$. Indeed, equation (9) can be written as

$$\frac{\alpha_{i1}}{\alpha_{i2}} \left(\frac{y_i - p x_{i1}}{x_{i1}} \right)^{1-\rho_i} = p + \frac{\beta_i \sigma_i \theta_{i1} (\theta_{i1} x_{i1} - \varepsilon_i - \mu_i)}{1 - \beta_i \sigma_i \theta_{i1} (\theta_{i1} x_{i1} - \varepsilon_i - \mu_i) x_{i1}} \cdot y_i \tag{10}$$

A number of implications follow from equation (9):

Proposition 3. *The food consumption of an individual who lives in affluence is:*

(a) decreasing in fitness sensitivity (σ_i),
(b) decreasing in the individual's degree of self-control (β_i),
(c) decreasing in the relative price of food (p),
(d) increasing in the preference for food (α_{i1}/α_{i2}),
(e) increasing in ideal BMI (μ_i)
(f) increasing in the individual's metabolic rate (ε_i).

The claims in Proposition 3 are intuitive and all follow from the trade-off between food consumption and fitness. We note that implications (a)-(e) also hold for the individual's BMI, $w_i^* = \theta_{i1} x_{i1}^* - \varepsilon_i$. The sixth implication, (f), in turn implies that, while food consumption is higher for faster metabolic rates, BMI will be lower. To see this, note that an increase in the metabolic rate ε_i reduces the right hand side of (9) for each value of x_{i1}. Thus the solution, x_{i1}^*, must increase. But suppose food consumption, x_{i1}^*, increases just enough to offset the increase in metabolic rate, ε_i, so that BMI remains the same. Then the marginal cost of food consumption (the right hand side) is at least as large as before, but the marginal benefit of food consumption (the left hand side) falls. Thus the associated BMI, w_i^*, must be somewhat lower in order to balance the equation. Since an individual with a higher metabolic rate will have BMI closer to his or her ideal as well as consumption closer to his or her unconcerned consumption, individuals with a faster metabolism, *ceteris paribus*, have overall higher welfare.[22]

We next examine the effect of income on BMI. In the absence of fitness concerns all goods are normal in our model. Hence, in the above special case of two goods, an individual who does not care about fitness will become fatter, the richer that individual becomes. However, a concern for fitness may render food inferior at high enough income levels. In other words the individual may become slimmer as his or her income rises. In particular, our parametric specification of the general model permits BMI to be increasing in income at low income levels, and decreasing in income at high income levels, depending on the 'substitutability' parameter ρ_i.

Proposition 4. *An individual's equilibrium BMI is increasing in his or her real income when $\rho_i \leq 0$. For $\rho_i > 0$, an individual's equilibrium BMI is decreasing in real income at all incomes above a certain level.*

(See Appendix for a proof.)

We illustrate the relationship between income and BMI for individuals living in affluence and varying ρ_i in Figure 1. The thick curve is drawn for $\rho_i = 0$, the increasing curves for $\rho_i = -0.5$, -1, and the non-monotonic curves for $\rho_i = 0.5$, 0.75 and 0.94.[23] Consumption of food decreases with income, at high income levels, when the two goods are sufficiently substitutable (ρ_i sufficiently large). Note that BMI is always increasing in income for an individual living below nutritional affluence. For an individual living in nutritional affluence, however, BMI is increasing in income at lower income levels and decreasing only at a higher levels of income at which the individual already consumes plenty of food and has BMI above ideal (see Figure 1).

[22] In the proposition we assume the individual lives in affluence, but the case where $w_i^o < \mu_i$ is similarly intuitive. The more an individual cares about fitness, σ_i, or the more self-control she has, β_i, the higher will be her consumption of the weight enhancing good and so the closer she will be to ideal BMI. As in part (f), an individual with higher metabolic rate will consume more and will still have lower BMI, but now her overall welfare will be lower. In this sense a faster metabolism is advantageous in a affluent society but disadvantageous in a poor society. All other parts of the proposition remain the same.

[23] Figure 1 illustrates the parameter values $\alpha_1 = \alpha_2$, $p_1 = 1$, $p_2 = 2$, $\theta = 1$, $\mu = 22.5$, $\varepsilon = -22.5$ and $\beta\sigma = 1$.

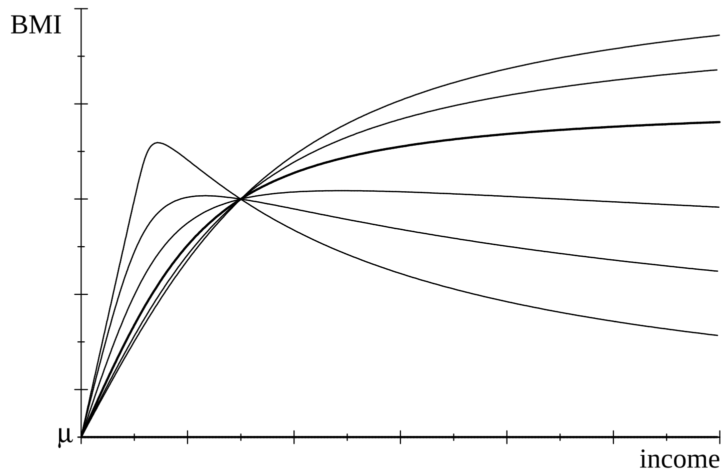

Figure 1: Equilibrium BMI as a function of income, for different levels of substitutability of goods

The intuition for this result is that richer individuals, in equilibrium, place more importance on fitness relative to consumption and therefore are willing to 'pay' more (in whatever form that cost takes) to increase their fitness. We do *not* assume that richer individuals value physical fitness more than poorer individuals. Instead, this occurs endogenously. All consumption goods being normal, richer individuals consume more and so, with diminishing marginal utility from consumption, in equilibrium attach a lower marginal utility to consumption than the poor. If poor and rich individuals were to have the same level of physical fitness, and the poor were in equilibrium, then the marginal consumption utility of the poor would equate their marginal fitness utility while the marginal consumption utility of the rich would fall short of their marginal fitness utility. The rich would thus not be in equilibrium; they could increase their total utility by marginally switching away from consumption of weight-enhancing food towards other goods, leading to a marginal improvement of fitness that would outweigh the marginal loss in consumption utility. Thus, the wealthier an individual becomes, the more the trade-off between the two utility components (consumption and physical fitness) falls in favor of physical fitness. To put it in everyday terms, the rich are better able to satisfy their consumption desires and so can concern themselves more with their own fitness relative to poorer individuals who struggle more with satisfying their consumption desires and so cannot put as much emphasis on personal fitness.

We believe the above qualitative observations carry over to economies with more than two goods, also when some goods may have a negative effect on BMI, such as going to the gym. Indeed, the non-monotonicity may be even more pronounced when there are more variants of food, some of which are less weight-enhancing, and when there are goods (such as a sports) that are weight-reducing. The last claim is substantiated in the following remark.

Remark 4. *Suppose that a third, weight-reducing good ("gym") is added to the above specification, see Remark 3. Numerical simulations for the same parameter values as in Figure 1 show that the presence of a weight-reducing good enhances fitness and strengthens the negative effect of income on BMI for moderate to high incomes. Moreover, this negative effect persists even when goods are complements, rather than substitutes (that is when ρ_i is slightly negative). The reason is simply that wealth enables a life-style that allows for somewhat higher food intake (and thus higher consumption utility) in combination with more expenditure on gym/sports.*[24]

4. Empirical observations

How do the predictions of the model compare with empirical observations? The US, UK, and other developed countries exhibit predominantly negative relationships (sometimes inverse U-shaped) between income and BMI within the population at any given time.[25][26] We briefly examine in some more detail the relationship in 1999 between income and BMI in the US using data from the National Health and Examination Nutrition Survey (NHANES).[27] Figure 2 plots the mean BMI of 25 to 65 year old individuals for different incomes and estimates a nonparametric fit of the data using locally weighted scatterplot smoothing.[28] The relationship between income and BMI indicated by the data in Figure 2 is suggestive of the relationship predicted by proposition 4 when weight-enhancing food is substitutable to some degree with other goods. Figure

[24] More exactly, the parameter values the graph is drawn for are $p_1 = p_3 = 1$, $p_2 = 2$, $\mu_i = 22.5 = -\varepsilon_i$, $\alpha_{i1} = \alpha_{i2} = 0.45$ (and thus $\alpha_{i3} = 0.1$), $\theta_{i1} = 1$, $\theta_{i2} = 0$, $\theta_{i3} = -0.5$.

[25] Lakdawalla and Philipson (2009) find BMI to be decreasing in income for women, and increasing at low levels of income and then decreasing at higher levels of income for men, (US data between 1976 and 1994).Chang and Lauderdale (2005) find BMI is decreasing in income (or inverse U-shaped) for all groups excluding Black and Mexican American men. Chou et al. (2004) show declining BMI and obesity levels with increasing income in the US.

[26] There appear to be some gender differences in the relationship between income and BMI, which we discuss below. Nevertheless, each gender fits the pattern discussed in this section.

[27] BMI is measured and incomes are self-reported. We set income in the first income bracket ($0-$5,000) to $5,000, the last income bracket ($75,000 plus) is set at $80,000, and income for all other brackets is set at the midpoint of the particular bracket.

[28] Mean BMI is adjusted to account for the complex survey design used in NHANES. We use stata bandwith of 0.4 for the locally weighted scatterplot smoothing.

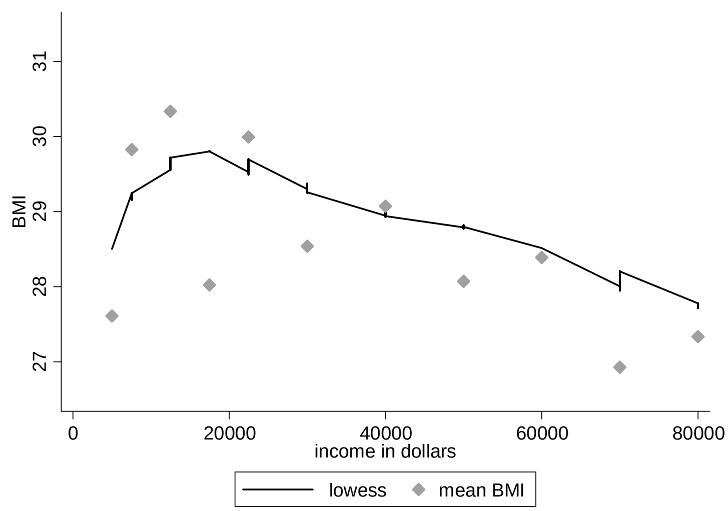

Figure 2: The relationship between BMI and income for men and women ages 25 to 65 in the US in 1999

3 plots the relationship between income and BMI using the two-good model and numerical values chosen to fit the US data.[29] See appendix for details of how the parameter values have been estimated.

While the relationship between income and BMI is predominantly negative at a given time, the BMI of all income groups has increased over time. Chang and Lauderdale (2005) examine US data from 1971 to 2002 and find BMI increasing over time for all income groups, while, at any given point in time, BMI is decreasing, or inverted U-shaped, in income. Propositions 3 and 4 provide an explanation for this "paradox". The first phenomenon is in line with Proposition 3, in so far as the relative price of weight-enhancing food (food rich in sugar and fat) has largely decreased over time.[30] This relates to work by Lakdawalla et al. (2005) and Cutler et al. (2003) who stress the importance of technological change and the effect this has had on reducing the price of calories[31] The second phenomenon is in line with Proposition 4 and Figure 1, under the arguably reasonable assumption that substitutes to weight-enhancing foods have

[29]Good 1 consists of all food items, excluding very healthy foods (lean meats, fish, fruit and vegetables). Good 2 consists of all other non-durable goods including very healthy food items.

[30]In the UK the only group for which obesity levels are found to be falling over time are females in the highest social class (out of six classes) (Mazzocchi, Traill and Shogren, 2009). This could be explained if income in this class has been increasing sufficiently fast relative to reductions in the price of food.

[31]This includes a reduction in actual cost, time cost, and well as an increase in the cost of expending calories, which we do not explicitly model here (see Lakdawalla et al., 2005).

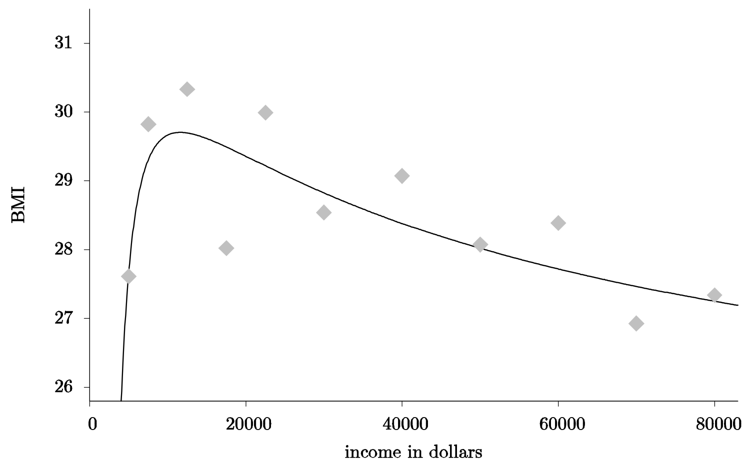

Figure 3: A numerical specification of the two-good model chosen to fit mean BMI in the US 1999

been, and still are available. The model implies that technological growth that reduces the price of calories will increase weight across the board, while general economic growth that makes people richer will reduce weight across the board (at least for those with income beyond the level at which BMI peaks). It follows that economic growth felt by all income groups could reduce the overweight and obesity problem of countries such as the US, but if this economic growth is accompanied by further technological improvements (or other events) that reduce the price of food, a reduction in weight levels is not guaranteed.

The third empirically observable phenomenon in the relationship between BMI and income comes from comparing across countries. The least developed countries have a predominantly positive relationship between BMI and income, while the most developed countries have a predominantly negative relationship. The model predicts what the relationship between BMI and income should look like for countries with different incomes. In a poor country, where the population lives below nutritional affluence there will be a positive relationship between income and BMI with the richest in the population being the fattest and the poorest the thinnest. Suppose that population as a whole gets gradually richer. Eventually we will see the fattest person in the population move down the income distribution (an inverse U-shape with the peak moving down) such that when the population as a whole is rich enough the relationship between income and BMI will be negative for the whole income distribution. Thus the richest person in a rich country may be heavier than the poor of a poor country but lighter than the poor in his or her own country.

For such a non-monotonic relationship between BMI and income, food must be substitutable, at least to some degree, with other goods. Suppose unhealthy and healthy food increase BMI but healthy food increases BMI to a lesser degree, then the non-monotonic relationship between BMI and income holds if healthy foods and unhealthy foods are substitutable to some degree.[32] Casual observation suggests that as people get richer they often substitute unhealthy cheap food, say hamburgers, for healthier more expensive food, such as sushi. Indeed Zheng and Zhen (2008) find estimates from the US and Japan that indicate that healthy and unhealthy foods are substitutes, while Pieroni, Lanari and Salmasi (2011), using Italian data, find 'nontrivial' levels of substitution between healthy and unhealthy foods.[33] We suspect the reality is more complex. Richer individuals may not only substitute to eat more healthy foods, but may substitute for higher quality and tastier healthy foods as well. For example, in the UK not only does the number of pieces of fruit and vegetables purchased increase with income, but so does the unit price paid. In 2002/2003 those in the lowest income quartile spent on average £0.153 per kilo on fruit and vegetables while those in the highest income quartile spent £0.187 (Mazzocchi et al., 2009).

We conclude this section by first comparing empirical evidence on self-control with the findings of the model. We then do the same for empirical evidence on gender differences in food consumption and BMI. Recall from proposition 3 that lower self control results in higher BMI, *ceteris paribus*. Moreover, the higher the income, the more sensitive BMI is to one's degree of self-control, since richer individuals with less self control when making their consumption decisions, can afford to, and will, buy more food. In fact the interaction between self-control, income and BMI is complex: at low levels of self-control, higher income is bad for BMI (increasing BMI), however at higher levels of self-control, higher income reduces BMI. Empirical evidence shows that the upper tail of the BMI distribution in the US and UK has been growing much faster than, for example, the median. As others have suggested (Cutler et al., 2003, Mazzocchi et al., 2009), it appears that certain portions of the population may be more susceptible than others to obesogenic environments. Our model suggests that where an individual has low self-control (or low concern for fitness) that individual will

[32] In the model we present this would assume individuals gain weight from unhealthy foods but not from healthy foods. This can be relaxed so that the rate of weight gain from healthy food is lower than that from unhealthy food.

[33] While the relative price of unhealthy foods, in comparision with healthy foods, impacts BMI, change in this relative price is unlikely to be a major cause of the obesity epidemic, according to evidence from Gelbach, Klick and Stratmann (2009) and Zheng and Zhen (2008).

be particularly sensitive, in terms of food consumption and BMI, to changes in income and food prices.

Empirical evidence also consistently shows differences in the behavior of men and women in relation to BMI. Studies find a stronger negative effect of income and education on the weight of women while the relationship between BMI and income for men tends to be inverse U-shaped if determined (Lakdawalla and Philipson, 2009, Chang and Lauderdale, 2005). Papers on peer effects suggests that women may be more sensitive than men to the weight of their peers (Trogden et al., 2008, Renna et al., 2008). Seemingly in contrast to this, Pieroni et al. (2011), on examining consumption, find substitution of unhealthy foods for healthy foods following price changes is stronger for Italian male household heads than female household heads. Within our model a lower fitness-sensitivity (lower σ) could explain all three phenomena: a flatter or more inverse U-shaped relationship between BMI and income, a stronger response to changes in food prices, and weaker peer effects. Alternatively the first two phenomena could be explained by a higher BMI ideal. Thus these gender differences in BMI would be explained if men are less concerned about deviating from their ideal BMI than women, an arguably plausible assumption.

5. Fat taxes

We here briefly consider the theoretical effect, in our model, of a tax on weight-enhancing food, a "fat tax". In the two-goods model specification, let thus the food price paid by the consumer be $(1+t)\,p_1$, where $t \geq 0$ is the (value-added) tax-rate on food. Suppose that this tax is collected by a government agency that redistributes the tax revenue in the form of a lump-sum transfer T to each individual. Individual consumption is evidently affected by this tax and transfer, and each individual's consumption, x_{1i}, satisfies equation (10):

$$\frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{y_i-(1+t)\,px_{i1}}{x_{i1}}\right)^{1-\rho_i} = (1+t)\,p + \frac{\beta_i\sigma_i\theta_{i1}(\theta_{i1}x_{i1}-\varepsilon_i-\mu_i)}{1-\beta_i\sigma_i\theta_{i1}(\theta_{i1}x_{i1}-\varepsilon_i-\mu_i)x_{i1}}\cdot(y_i+T)$$

for $i = 1, .., n$. The government's budget balance equation can be written as

$$nT = tp\cdot\sum_{j=1}^{n} x_{1j}$$

For any given tax rate $t \geq 0$ and producer prices p_1 and p_2, the resulting consumption pattern, and associated BMI-distribution, is found by simultaneously

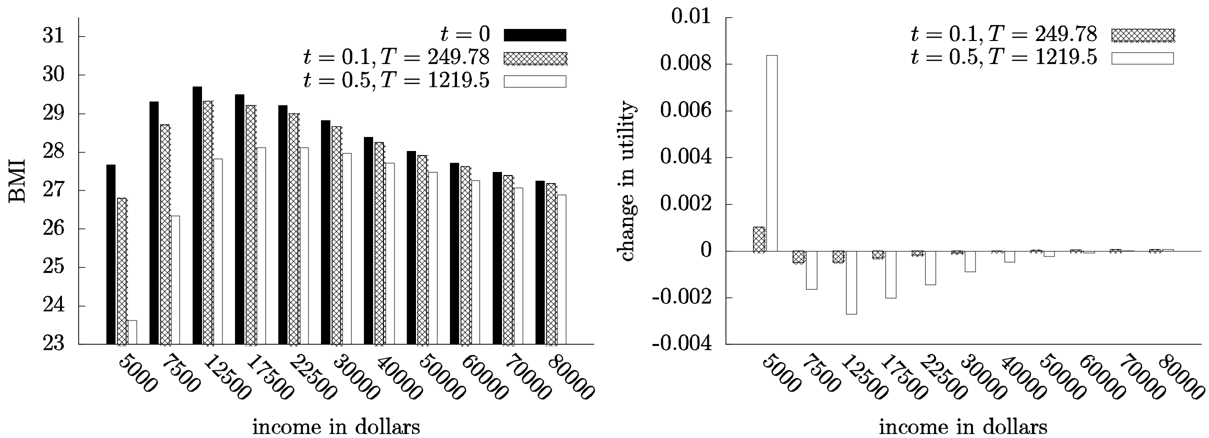

Figure 4: The effect of a tax on food with redistribution

solving these $n + 1$ equations.[34]

Using the parameters estimated in Figure 3 we calculate the effects of a 10% and 50% tax on good 1, weight-enhancing food. The first plot in Figure 4 shows BMI levels for a range of incomes before a tax on food and after a tax on food where the revenue from that tax is redistributed evenly amongst the population as described above. The income distribution is estimated from the Consumer Expenditure Survey in 1999.

From proposition 3 we know that a tax on food will reduce BMI at all incomes and we see this continues to be true even after redistribution for this particular calibration (Figure 4). Observe that a tax on food reduces BMI most for those with the lowest incomes, who also tend to be those with the highest BMI. This result is supported by evidence from Pieroni, Lanari and Salmasi (2011) who find somewhat higher cross-price elasticities of substitution between healthy and unhealthy foods for poorer households in Italy relative to richer households.

The US data indicates that those who consume the most calories are those at the bottom of the income scale, thus suggesting we should pay careful attention to the welfare effects of such a tax. The second plot in Figure 4 shows the change in utility for each income group after the tax on food when the revenue from

[34] Clearly producer prices may change when such a tax and transfers are introduced. In order to account for the full effect, one has to solve for the associated general equilibria, as defined above. The general-equilibrium effects of a fat tax would seemingly be even stronger than reported here, since a decline in the demand for food would (under decreasing returns to scale in food production) arguably lead to an increase in the producer price and hence an even higher consumer price.

that tax is redistributed evenly amongst the population. We observe that utility falls for those on low incomes and rises for those on high incomes (as well as for the very poorest). Nevertheless, the magnitude of these changes in utility are very small: the largest fall in utility happens for the income level \$12,500 (at a tax of 50%) and is equivalent to a drop in income of less than \$60. In summary, a tax on weight-enhancing foods will lower BMI, particularly for income groups where BMI is highest, but such a tax has a predominantly negative impact on the welfare of the poor and should be accompanied by careful redistribution.

Remark 5. *A lump-sum transfer is not the only possible way to redistribute the revenues from a fat tax. A subsidy on non-weight enhancing or health-improving goods is another possibility. Suppose the revenue from the tax on good 1 is paid back to the consumers as a subsidy on good 2.*[35] *With the same tax rates as above (10% and 50%), we find that BMI falls for all individuals, especially for those with low incomes. Comparing the welfare effects of the two policies, the subsidy scheme has a stronger negative effect on lower income groups compared to the lump-sum transfer scheme; the fall in total utility for income group £12,500 when* $t = 0.5$ *is more than tenfold the drop in total utility for the tax-transfer policy. This is because a policy which subsidizes other goods is heavily weighted towards those who consume more of those other goods: the rich.*[36]

Our model points to a further potential policy recommendation. While falling food prices and the accompanying general rise in BMI have been attributed to technological improvements (Lakdawalla et al., 2005, and Cutler et al., 2003), technological improvements need not necessarily be weight-increasing. If technology were used to produce healthier and tasty foods that are highly substitutable with unhealthy foods, then our model suggests this would lower BMI levels for some portions of the population (see Figure 1).[37] This appears to be

[35] This follows a similar set up to tax and redistribution. Each individual's consumption, x_{1i}, satisfies equation (10) for a tax t on good 1 and subsidy s on good 2, with the government's budget balance as $tp\sum_{j=1}^{n} x_{1j} = s\sum_{j=1}^{n}(y_i - px_{1j})$.

[36] This simple policy experiment neglects the potential effect on market prices from the tax and transfer. The model is easily extended to include such effects, by way of introducing supply functions for the goods.

[37] Note that Figure 1 indicates that the BMI of the poor could rise were goods to be made more susbstitutable. In this instance poorer individuals move to substitute unhealthy food for healthy food (since unhealthy food has become more of a substitute for healthy food). However current research is working towards making healthier foods to susbtitute for unhealthier ones and not the other way around (i.e. healthier potato chips to substitute for current less healthy potato chips), and so this potential downside to making food more substitutable may not be relevant.

happening to some degree: the UK government currently funds research projects in collaboration with food companies with the aim to develop new technologies and ingredients to produce healthier snacks and other foods.[38]

6. Peer effects

In this section we explore what happens, in our parametric model, when an individual's valuation of her own fitness is influenced by her peers, in either of two distinct ways; by an influence on the ideal and by an influence on one's sensitivity to deviations from one's ideal, respectively.

6.1. Peer effect on BMI ideal. Suppose that an individual's ideal BMI lies between a "medical ideal", μ^0, and the average BMI of others in i's peer group,

$$\mu_i\left(\mathbf{w}_{-i}\right) = \left(1-\gamma_i\right)\mu^0 + \gamma_i \bar{w}_{-i}$$

where $\gamma_i \in [0,1]$ is the *social sensitivity* of individual i and $\bar{w}_{-i}$ is a weighted average BMI,

$$\bar{w}_{-i} = \sum_{j \neq i} \tau_{ij} w_j$$

where the parameters $\tau_{ij} \geq 0$ are i's *peer factors*, representing the importance that individual i places on individual j in her BMI-ideal formation, where $\sum_{j\neq i} \tau_{ij} = 1$. In the two-goods case, the necessary first-order condition for population equilibrium can then be written

$$\frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{\theta_{i1}y_i}{w_i+\varepsilon_i}-p\right)^{1-\rho_i} = p + \frac{\beta_i\sigma_i(w_i-\mu^0-\gamma_i\left(\bar{w}_{-i}-\mu^0\right))}{1-\beta_i\sigma_i\left(w_i+\varepsilon_i\right)\left(w_i-\mu^0-\gamma_i\left(\bar{w}_{-i}-\mu^0\right)\right)}\cdot\theta_{i1}y_i$$

In the extreme case when individual i is completely insensitive to others' BMI ($\gamma_i = 0$), this is the same equilibrium condition as in the absence of peer effects. In the opposite extreme case when individual i is maximally sensitive to others' BMI (and doesn't care at all for the medical ideal, $\gamma_i = 1$), we obtain

$$\frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{\theta_{i1}y_i}{w_i+\varepsilon_i}-p\right)^{1-\rho_i} = p + \frac{\beta_i\sigma_i(w_i-\bar{w}_{-i})}{1-\beta_i\sigma_i\left(w_i+\varepsilon_i\right)\left(w_i-\bar{w}_{-i}\right)}\cdot\theta_{i1}y_i$$

[38]This includes research funding for Pepsico to develop new starch technologies to produce baked snacks and Macphie of Glenbervie, a baking company, to research the production of healthier baked foods using ultrasound. Taken from 'Junk food companies paid by taxpayer to develop healthier products', The Telegraph. http://www.telegraph.co.uk/health/healthnews/9498868/Junk-food-companies-paid-by-taxpayer-to-develop-healthier-products.html

In the special case of a homogeneous population, and maximal social sensitivity, the unique symmetric equilibrium is that everybody obtains the same BMI and this BMI is the (commonly shared) unconcerned BMI: $w_i = \bar{w}_{-i}$ for all individuals i and hence the second term on the right-hand side vanishes. In a nutritionally affluent society, everybody will then be just as obese as if they did not care at all about the fitness effects of their consumption.[39]

There are a number of reasons why this route might not be the most important channel for peer effects. First, BMI levels portrayed as ideal on television and in the media are generally within the medically healthy range (sometimes below healthy), despite the fact that the majority of the population in, for example, the US are either overweight or obese. Second, a study by Rand and Resnick (2000) found that while many people's actual body weight did not match their ideal, still 87% of subjects 'considered their own body size socially acceptable.'

6.2. Peer effect on BMI sensitivity. As suggested by the study of Rand and Resnick (2000), another channel for peer effects goes via individuals' cost of *deviation* from their ideal BMI. The more those in an individual's peer group (family, neighborhood, work-place) deviate from the individual's ideal BMI, the less the individual may be concerned by her own deviation from her ideal BMI. That is, a person surrounded by fat people may be less concerned with her body weight than had her peers been thin.[40]

Formally, let each individual's fitness sensitivity, σ_i, depend on others' BMI as follows:

$$\sigma_i \left(\mathbf{w}_{-i}\right) = \left(1 - \gamma_i\right) \sigma_i^o + \gamma_i \prod_{j \neq i} f_i \left(w_j\right)^{\tau_{ij}} . \tag{11}$$

The first term, $\sigma_i^o \geq 0$, is i's basic sensitivity to own fitness. The second term represents the peer effect and is decreasing as the BMI of i's peers deviate further from i's ideal BMI:

$$f_i \left(w_j\right) = \exp\left(-\lambda_i \frac{\left(w_j - \mu_i\right)^2}{2}\right).$$

This factor measures how close another individual j's BMI is to i's ideal, where $\lambda_i > 0$ represents i's sensitivity to this deviation. The parameters τ_{ij} are again

[39] Blanchflower, Oswald and Van Landeghem (2009) examine a different set up whereby individuals have higher utility the thinner they are relative to average weight in the population.

[40] For example, penalties for being overweight in marriage markets (Carmalt et al., 2008) and in labor markets (Cawley, 2004) may be relative.

i's peer factors. The quantity $\Pi_{j \neq i} f_i (w_j)^{\tau_{ij}}$ is thus the peer-factor weighted geometric mean of how close others are to i's BMI ideal. The parameter $\gamma_i \geq 0$ is again i's *degree of social sensitivity.*

Under the endogenization (11), the first-order condition for i's choice of food consumption, here written in terms of her BMI w_i, becomes

$$\frac{\alpha_1}{\alpha_2} \cdot \left(\frac{\theta_{1i} y_i}{w_i + \varepsilon_i} - p \right)^{1-\rho_i} =$$

$$= p + \frac{\theta_{1i}\beta_i \left[(1-\gamma_i)\,\sigma_i^o + \gamma_i \;\exp\left(-\lambda_i \sum_{j \neq i} \tau_{ij} \left(w_j - \mu_i\right)^2 /2 \right) \right] (w_i - \mu_i) y_i}{1 - \beta_i \left[(1-\gamma_i)\,\sigma_i^o + \gamma_i \;\exp\left(-\lambda_i \sum_{j \neq i} \tau_{ij} \left(w_j - \mu_i\right)^2 /2 \right) \right] (w_i - \mu_i)(w_i + \varepsilon_i)} \tag{12}$$

for all $i \in 1,..,n$. Each individual treats the others' BMI-values (w_j for $j \neq i$) as exogenous when deciding upon her own consumption (and hence her own fitness). This equation is the same as that in (10), when written in terms of BMI, the only difference being we substitute for endogenous σ_i. Hence, for given BMI-values for all others, equation (12) uniquely determines w_i. It follows immediately from Proposition 1 that the system of equations (12) has at least one solution, by which we mean a population BMI profile $\mathbf{w}^* = (w_1^*, .., w_n^*)$, for any combination of positive parameter values.

Homogeneous population. Depending on the strength of the social sensitivity parameter (γ_i) there may be more than one equilibrium population BMI profile. If others' fitness is high (low), and the individual is sufficiently socially sensitive, then she/he may choose a consumption bundle that leads to high (low) own fitness. We illustrate this possibility for a homogenous population in symmetric equilibrium. The first-order condition (12) for a common BMI level w to be an equilibrium then becomes:

$$\frac{\alpha_1}{\alpha_2} \left(\frac{\theta_1 y}{w + \varepsilon} - p \right)^{1-\rho} = p + \frac{\beta \left((1-\gamma)\,\sigma^o + \gamma e^{-\lambda (w-\mu)^2/2} \right) (w-\mu)\theta_1 y}{1 - \beta \left((1-\gamma)\,\sigma^o + \gamma e^{-\lambda (w-\mu)^2/2} \right) (w-\mu)(w+\varepsilon)}. \tag{13}$$

The thick solid line in Figure 5 shows the associated equilibrium correspondence that to each level of the relative food price, p, attaches the corresponding equilibrium population BMI level or levels. Figure 5 is drawn for the parameters calibrated in Figure 3.[41] We see that the equilibrium BMI is unique and high

[41] More exactly: $\beta = 0.00644$, $\lambda = 1$ and an income y of \$30,000, with $\gamma = 0.86957$ for the solid curve and $\gamma = 0.7$ for the dashed curve.

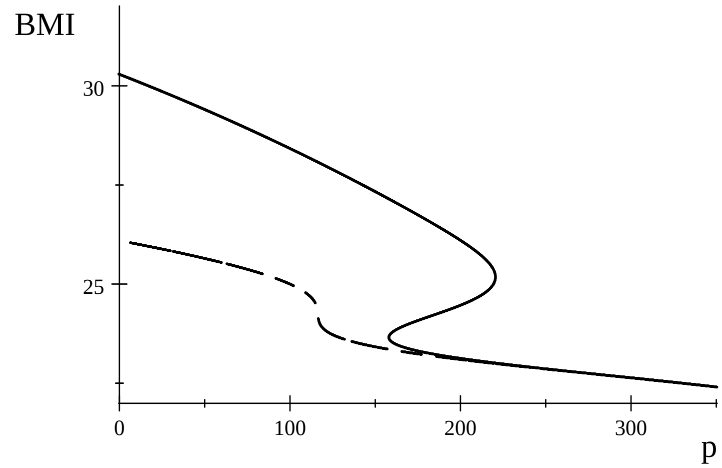

Figure 5: BMI as a function of the relative price of food

at low relative food prices, $p < 158$, unique and low for high relative prices, $p > 221$, while for intermediate prices, between these two price levels, there are three equilibrium BMI-values. Of these, only the top and bottom equilibria are stable under adaptive consumption adjustments.

Multiple equilibria arise as a result of peer effects. When individuals are socially sensitive and everyone else in the population is fit then fitness sensitivity, σ, is high. When everyone else in the population is fatter fitness sensitivity falls, all else equal. It follows that there may be both an equilibrium where people consume less food and remain relatively fit, meaning both the marginal benefit of food consumption and the marginal cost of BMI are high; as well as an equilibrium where people consume more food and have higher BMI, meaning the marginal benefit and marginal cost of food consumption are both lower.[42] Whether or not multiple equilibria exist depends on the level of social sensitivity, γ_i. Higher levels of social sensitivity than that documented in Figure 5 result in multiple equilibria over a wider range of prices. By contrast, low levels of social sensitivity will result in a unique equilibrium at each price level, although there may still be a particularly fast rise in BMI within a particular price range, as illustrated by the dashed line in Figure 5.

Our model suggests the possibility of hysteresis. Suppose that the relative price of food is high and decreases continuously over time. The solid line in Figure 5 shows that the population BMI-value would necessarily make a sudden

[42] Typically, there will also exist an intermediate equilibrium, as seen in the diagram. However, that equilibrium is unstable with respect to perturbations of (perceptions of) others' BMI, and is thus empirically irrelevant.

upward jump at some intermediate price level, the most likely candidate for such a jump (under smoothly adaptive expectations-formation) would be at the price where the lower fold of the equilibrium correspondence takes place, or $p = 158$. In other words, we should expect a drastic increase in the population BMI-value as the price gradually decreases in this critical price zone. If we were then to reverse the price movement to a continuous increase, BMI would suddenly jump down to the lower branch (under smoothly adaptive expectations-formation), but this time at a much higher relative price than the mentioned upward jump; this time at $p = 221$.[43] We discuss implications for the pattern of population weight gain over time in relation to the obesity epidemic in Section 7.

Heterogeneous population. We conclude by briefly considering peer effects in a heterogeneous population. For the sake of clear comparison with the numerical example above, suppose that individuals differ only in income. Using the same income brackets as in Figure 4, and treating each income group as homogeneous, we have eleven income groups, $k = 1, 2, .., 11$, of population sizes n_k and with (representative) incomes $y_1 < y_2 < ... < y_{11}$ (the same as in Figure 4). There is a wealth of evidence that individuals form more ties with those who are similar to them and so, for the sake of illustration, we suppose that the influence of one individual on another is exponentially decreasing the more their incomes differ.[44] Peer effects can take on a variety of forms and to illustrate this we also allow for the possibility that the rich are more influential that the poor. Specifically, for an individual in income group k, let the total influence (or *peer effect*) of individuals in income group h be given as[45]

$$\tau_{kh} = \frac{n_h y_h e^{-\delta|y_k - y_h|}}{\sum_m n_m y_m e^{-\delta|y_k - y_m|}}, \tag{14}$$

[43] This reasoning presumes an arguably plausible form of expectational inertia, see Lindbeck, Nyberg and Weibull (2003) for a more detailed analysis of such dynamics in the context of taxation and social norms.

[44] There is evidence of strong homogeneity in education, occupation and class among social ties including friends, partners, neighbors and more. For a review see McPherson et al. 2001. Whether or not ones social ties are those who exert the most influence over an individual's perception of the importance of physical fitness and overweight is much harder to determine empirically.

[45] We here simplify by including the individual him- or herself among the peers in her own income group. The precise expression would replace n_k by $n_k - 1$. However, for n_k large, the difference is negligeable.

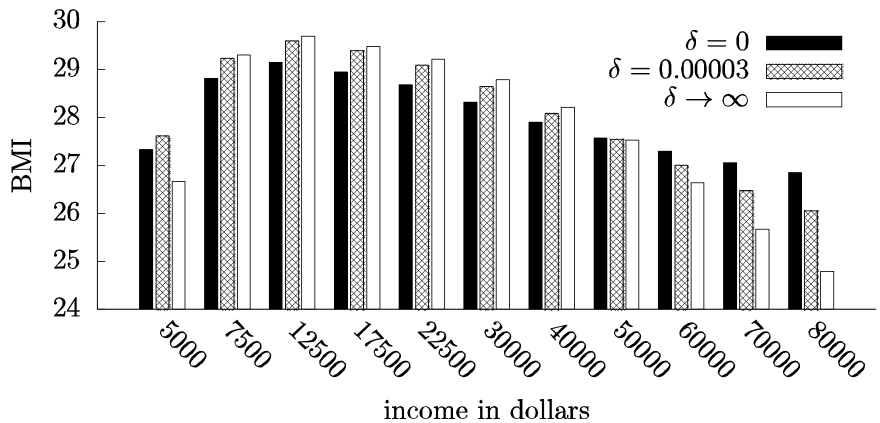

Figure 6: BMI by income group with varying peer effects

where $\delta \geq 0$ is the *decay factor* by which the peer effect diminishes as incomes get further apart.[46] The case $\delta = 0$ represents a "global" peer group, where each individual is socially influenced, in her view of her own body weight, by all others in society alike (with a higher weight placed on the rich). The limit as $\delta \to +\infty$, represents the opposite case of "local" peer groups, where individuals are influenced only by those in their own income group.

The following equations, for $k = 1, .., 11$, are the necessary first-order conditions for an equilibrium in which all individuals in each income group k have the same BMI, w_k:

$$\frac{\alpha_1}{\alpha_2}\left(\frac{\theta_1 y_k}{w_k + \varepsilon} - p\right)^{1-\rho} = p + \frac{\beta\left[\sigma^o + \gamma \exp\left(-\lambda \sum_h \tau_{kh}\left(w_h - \mu\right)^2/2\right)\right](w_k - \mu)\theta_1 y_k}{1 - \beta\left[\sigma^o + \gamma \exp\left(-\lambda \sum_h \tau_{kh}\left(w_h - \mu\right)^2/2\right)\right](w_k - \mu)\left(w_k + \varepsilon\right)},$$

with the (exogenous) peer-factors τ_{kh} given in (14). Figure 6 plots the parameter values and relative price of food as in Figure 4, and with , $\beta = 0.84$, $\sigma^o = 0.001$, $\gamma = 1$ and $\lambda = 0.6$. The black bars represent the case of a "global" peer group $\delta = 0$, the hatched bars $\delta = 0.0003$ and the white bars "local" peer groups when $\delta \to +\infty$ ($\tau_{kh} = 1$ iff $h = k$, $\tau_{kh} = 0$ otherwise). We see in the diagram that moving from "local" to "global" peer groups tends to even out the BMI distribution; the rich and very poor increase their BMI while low- and middle-income earners reduce their BMI.

Our model of peer effects suggests that population BMI changes should be associated with changing perceptions of what constitutes acceptable body

[46] Expression (14) without the terms y_h and y_m represents the case where rich and poor are equally influential: $\tau_{kh} = \frac{n_h e^{-\delta|y_k - y_h|}}{\sum_m n_m e^{-\delta|y_k - y_m|}}$.

weight. Burke et al. (2010) find that individuals with either normal BMI or who are overweight are less likely to perceive themselves as overweight in 2000 compared to 1990. Further, Oswald and Powdthavee (2007) find that, at a given BMI, richer individuals are more likely to perceive themselves as overweight compared to poorer individuals. This would be consistent if, as above, individuals are more influenced by those in their income bracket.

7. The obesity epidemic

In this section we return to the dynamics of population weight gain. Empirically, obesity levels in the US remained relatively flat between 1960 and 1980, but rocketed between 1980 and 2000. Between 1960 and 1980 the percentage of obese in the United States was relatively stable, rising just 1.5% from 13.4% to 15%. By 1994, however, the population share of obese had grown to 23% and by 2000 obesity levels had doubled to 31% (Flegal et al. 2002).[47] The UK had a similarly sharp increase in obesity levels but from a lower starting point: between 1960 and 1980 obesity levels for men and women in the UK grew from 1% for men and 2% for women to 6% and 8% respectively; by 2000, 21% of men and 21.4% of women were obese.[48][49] Similarly, mean BMI rose less than 0.7 BMI points between 1960 and 1980 but rose more than 3 BMI points between 1980 and 2005.[50] Mean BMI This sharp rise in BMI is all the more surprising because it happened in populations that were already at and above healthy weights and is associated with a significant worsening of health. Understanding what caused this sharp rise in obesity from 1980 may be key to tackling the associated public health challenges faced by a growing number of countries.[51]

One can think of many possible causes of the rise in obesity since 1980; however most of the possible causes that spring to mind do not reconcile with the facts. A decline in physical workplace activity is an unlikely candidate since

[47] Flegal et al. (2010) find the percentage of obese had increased to 33.8% in 2008 and suggest this may indicate a decline in the rate of increase.

[48] http://www.telegraph.co.uk/health/healthnews/7307756/Obesity-rates-20-per-cent-higher-now-than-in-the-1960s.html

[49] Taken from *OECD.StatExtracts (* under: non-medical determinants of health, bodyweight, measured obesity levels).

[50] National Health and Nutrition Survey. See also Ljungvall and Zimmerman (2012).

[51] This is not to say that 1980 to 2000 is the only period of fast growth in population BMI in the US (see Komlos and Brabec, 2011). However, earlier periods of fast growth are associated with the general population below or within healthy weights. Our model would predict fast growth until the population is at healthy weight then slower growth as the population moves above a healthy weight, followed by a fast increase in population weight when the population is already at an unhealthy weight.

there was already a significant decline in strenuousness of market labor between 1960 and 1980; similarly the increase in labor saving devices in the home was larger between 1960-1980 than 1980-2000 (Finkelstein et al. 2005). Using the same argument, the biggest change in television viewing occurred between 1965 and 1975, and cars had largely replaced other methods of transport by 1980 (Cutler et al., 2003). Indeed Cutler et al. (2003) examine daily food intake and energy expenditure in the US and conclude that the most plausible explanation for the steep increase in obesity since 1980 is caloric intake and not caloric expenditure.[52] Nevertheless, calories consumed at meals have not increased, making arguments based on either increased portion sizes or fattening meals at fast food restaurants implausible (op.cit.). Chou et al (2004) show that increases in the price of cigarettes contributed to approximately 20% of the increase in BMI and obesity levels between 1984 and 1999, implying that a reduction in smoking is unlikely to explain the obesity epidemic. Offer et al. (2010) propose that economic insecurity fuels stress which induces overeating, but there is no particular reason to think that stress might contribute to a sudden and steep increase in weight gain post 1980 but not before.

An obvious potential explanation for the obesity epidemic is that a fall in the real price of food between 1980 and 2000 caused people to consume more food, resulting in the steep increase in BMI. Cutler et al. (2003) show there were also substantial reductions in the time taken to prepare food in the home from the late 1970s. Nevertheless, there is scepticism as to whether the magnitude of the fall in the price of food over this period was enough to cause individuals to consume the amount of food needed to generate the observed increase in BMI. Cutler et al. (2003) judge that the elasticity of caloric intake with respect to the price of calories that is needed to explain the increase in calorie intake over this period is implausibly high.

Cutler et al. (2003) propose a related explanation for the obesity epidemic. They show that technological innovation in food processing and packaging made affordable, pre-prepared food much more readily available in the 1980s compared to the 1960s. This reduced not only the time cost of food but, if individuals discount hyperbolically, as food becomes more immediately available they are less able to resist it and in equilibrium will consume more. Cutler et al. (2003) pro-

[52] Finkelstein et al. (2005) on comparing a number of studies on calorie consumption conclude that 'the growth in energy intake is of sufficient magnitude to explain the rise in body weight' during the period from 1980. However, it should be noted that this is not true for ealier periods where reduction in calorie expenditure is an important factor (see Lakdawalla, Philipson and Bhattacharya, 2005, and Lakdawalla and Philipson, 2009).

pose that the technological change combined with hyperbolic time preferences drove the surge in BMI.

Our model with peer effects provides an explanation that could explain a fast increase in population BMI without a significant change in the environment. This is illustrated in Figure 5. Suppose the price of food is high at around $p = 300$ and population BMI is close to the ideal BMI of 22.5. Consider a gradual decrease in the price of food. Initially reductions in the price of food will be accompanied by only small increases in population BMI. This is because the population as a whole is very fit and so the individual cares a lot about her weight and will remain fit even as food becomes cheaper. However, as food prices continue to fall, there will eventually be a surge in population BMI. This occurs because as food prices fall further, others become more overweight, and the individual cares less about her own weight-gain; this dynamic feeds into itself such that at some price level there will be a fast increase in population BMI. Thus our model suggests that when food prices are low enough even a small drop in the price of food can trigger a sharp rise in population BMI.[53]

But at what food prices would we expect to find multiple equilibria or see this sharp rise in BMI? Multiple equilibria or a surge in BMI can only occur when social influence is sufficiently strong. Importantly, the effect of social influence is increasing as the price of food decreases. It follows that we would expect to see multiple equilibria emerge only once the price of food is low enough. The argument mimics a previous argument: as the price of food falls, consumption of food and other goods increases, and thus a marginal unit of food has a larger impact on subutility from fitness relative to subutility from consumption. Because a marginal unit of food has a bigger impact on fitness, the fitness term becomes more and more relevant to decision making as the price of food falls. The final step is to note that as fitness becomes more important, the BMI of others also becomes more important in decision-making and so social influence plays a bigger role in driving equilibria.

[53]Note that an explanation based on peer effects (where σ is endogenously determined) and the explanation proposed by Cutler et al. (2003) are indistinguishable in our model. A hyperbolic discounter who moves into a world where food is more readily available (as described in Cutler et al., 2003) will now, in essence, discount future health effects at an even higher rate relative to consumption. In our set up, this would be modelled as an exogenous reduction in β. The peer effects explanation we present here involves an endogneous reduction in σ. A reduction in β or a reduction in σ cannot be distinguished in the model.

8. Fitness rank concerns

It has been argued that individuals are concerned with their fitness *rank* in their peer group (Oswald and Powdthavee, 2007, and Blanchflower et al., 2009).[54] The larger the fraction of my peers who are fitter than me, the less happy I am with my own fitness. This indeed matters for an individual's economic and social success in situations when fitness plays a role in competition (such as in sports, but arguably also in marriage and job markets). Thus it is not my absolute fitness that matters but whether I am fitter or less fit than my competitors. Our framework to here suggests that individuals care in absolute terms about their fitness. When we allow for peer effects, the fitness of others can increase or reduce the amount an individual cares about his or her absolute fitness. Similarly, if others' BMI determines the BMI level the individual considers to be ideal, his utility is determined by his absolute fitness with respect to this ideal. Suppose instead we adapt the current framework such that an individual does not care about his fitness *per se* but cares only whether he is more or less fit than others. This is similar to what we above called peer effects on BMI sensitivity, but, as we will see, requires a slightly different analysis.

One way to model rank-dependent preferences is to let an individual's fitness utility be of the form

$$v_i(\mathbf{w}) = e^{-\sigma_i \cdot [\Phi_i(w_i) - \Phi_i(2\mu_i - w_i)]^2/2}$$

where μ_i is i's BMI ideal (which may be fixed or socially influenced) and $\Phi_i : \mathbb{R} \to [0,1]$ is the cumulative population BMI distribution, among i's peers (set $\Phi_i(w) = 0$ for all $w \leq 0$). The "loss term" in square brackets is the population share of individuals in i's peer group who have a BMI that is closer to i's ideal than i's own BMI. For an individual whose BMI equals her ideal, $v_i(\mathbf{w}) = 1$, while in general $v_i(\mathbf{w}) \leq 1$. The individual's fitness utility is maximized when the individual is the fittest and minimized when he or she is the least fit within his or her peer group.

In a finite population, Φ_i is a step function, determined by the BMI profile $\mathbf{w}_{-i}$. However, if peer groups are relatively large, and/or individuals do not perceive others' body weight exactly, it makes sense to treat Φ_i as a continuously differentiable function (for example, a parametric curve fitted to the empirical distribution). The marginal utility from positive consumption of any good k

[54] The subsequent discussion and analysis presumes that each individual's peer group is a non-empty set of individuals, from the total population, allowing for the possibility of overlapping peer groups.

then becomes

$$\begin{aligned}\frac{\partial U_i(\mathbf{x})}{\partial x_{ik}} &= \alpha_{ik} x_{ik}^{\rho_i - 1} \cdot \left(\sum_{k=1}^{m} \alpha_{ik} x_{ik}^{\rho_i} \right)^{-1} \\ &\quad - \beta_i \sigma_i \theta_{ik} \cdot \left[\varphi_i(w_i) + \varphi_i(2\mu_i - w_i) \right] \cdot \left[\Phi_i(w_i) - \Phi_i(2\mu_i - w_i) \right]\end{aligned}$$

where, as before w_i is given by equation (3). In particular, if the BMI distribution among i's peers were (perceived by i to be) uniform and i's BMI were less than double her ideal, the second term would be proportional to $\beta_i \sigma_i \theta_{ik}(w_i - \mu_i)$, the same expression as was obtained before, see (6). Therefore, under certain conditions, although an individual cares only about rank, the individual optimizes as if he or she cared about fitness itself, as we originally modeled it. This provides some justification for our orginal framework even if one supposes that the individual cares only about rank and not at all about fitness in itself. However, in general, the expression is more complex. Without further assumptions, existence of equilibrium is not guaranteed. One way to proceed with this model specification would be to constrain Φ_i to have some parametric form (say, log-normal) and try to find, by way of a numerical algorithm, a population consumption profile $\mathbf{x}$ such that the above first-order condition is met for each individual i, with each Φ_i being fitted to the empirical BMI distribution of i's peers.

9. Conclusion

We present a rigorous and yet tractable microeconomic approach to the 'whats' and 'whys' of the obesity epidemic. Our model is centred around the individual's trade-off between the desire to consume and the desire to be physically fit. The relative simplicity of this set-up (given the complexity of the issues) allows us to examine the effects of prices and incomes on the BMI distribution and also allows us to examine certain social and psychological features which have been proposed as important factors behind obesity. Two features in particular have been much commented on: (i) the consumer may not have full self-control at the moment of consumption (and may discount ensuing negative fitness effects), and (ii) the presence of peer effects in an individual's valuation of her own fitness. Our model is transparent and thus straightforward to interpret and apply, and yet, we believe, rich enough to deepen the understanding of mechanisms at work in the obesity epidemic.

Our model's predictions appear to agree with stylized facts. First, when food prices fall BMI goes up. Second, even though BMI is increasing for all income groups as the price of food falls, we should expect to see, at any given point in time, BMI decreasing in income for incomes above a certain level. This result derives from the observation that richer individuals consume more and so attach a lower marginal utility to consumption. It follows that richer individuals, when facing the trade-off between increasing consumption utility or fitness utility at the marginal dollar, will choose to spend that dollar in a way that better favors fitness compared to poorer individuals. Thus richer individuals will substitute towards healthier goods while poorer individuals will consume more unhealthy food and will have higher (unhealthier) BMI. This speaks against a popular notion that obesity among the poor necessarily results from their lack of self-control (albeit our model permits both channels). The above marginal-utility argument also has important implications for the widely discussed policy of 'fat taxes': the model suggests that taxing unhealthy foods, if unaccompanied by income transfers, may have undesirable welfare consequences.

Finally, the model suggests a possible explanation for the obesity epidemic and the particular pattern the obesity epidemic has followed. If a person surrounded by overweight people is, by our assumption, less concerned with being overweight than one surrounded by fit people then, as the price of food falls, population BMI can be low and relatively stable but then shoot up dramatically, either through multiple equilibria (with a sudden jump from a low to a high BMI equilibrium) or, in the case of a unique equilibrium, continuously slide up very quickly. Social influence plays a minimal role in consumption decisions when the population is poor. However, as the price of food falls, the role of social influence rises and social factors contribute to determining the development of population BMI. It follows that once the price of food is low enough, multiple equilibria or a steep rise in BMI can occur. Thus the model suggests that the obesity epidemic need not have been caused by a sudden change in environment in the 1980's but, more simply, a gradual fall in the price of food over time that eventually caused population norms to change quickly and suddenly.

We believe our model can fruitfully be generalized and refined further and that it can also be used in empirical work, as a framework for structural modelling of movements in BMI-distributions. Estimated model-parameter values can then potentially be used to forecast future BMI-distributions and to evaluate policies aimed at reducing obesity.

10. Appendix

10.1. Proof of Lemma 1. To see that it follows from our assumptions, let $\mathbf{w}_{-i}$ be given, and suppose that such an individual chooses a consumption bundle $x_i^* \in B(p, Y_i)$ resulting in body weight $w_i^* = \phi_j(x_i^*) < \hat{w}_i(\mathbf{w}_{-i})$. By contrast, her unconcerned consumption, $x_i^o \in B(p, Y_i)$, results in body weight above her ideal; $w_i^o = \phi_i(x_i^o) > \hat{w}_i(\mathbf{w}_{-i})$. Since both consumption patterns meet her budget constraint, so does any convex combination of them. Since, moreover, her body weight is a continuous function, ϕ_i, of her consumption pattern, there exists a convex combination of the above two consumption patterns, a pattern $x_i \in B(p, Y_i)$, where she achieves her ideal body weight: $w_i = \phi_i(x_i) = \hat{w}_i(\mathbf{w}_{-i})$. At that point, her fitness utility is maximized. Since her consumption utility function, u_i, by hypothesis is strictly quasi-concave, her consumption utility is higher at x_i than at x_i^*.[55] A contradiction. Hence $w_i^* \geq \hat{w}_i(\mathbf{w}_{-i})$.

10.2. Proof of Proposition 1. For $\rho_i \in (0, 1)$, the first term in (5) is a concave function of x_i. To see this, first note that the sum inside the logarithm is the sum of concave functions of x_i, hence concave. Secondly, the logarithm of a positive concave function is concave. When $\rho_i < 0$, the first term in (5) is a also a concave function of x_i. To see this, note that the sum inside the logarithm is the sum of convex functions of x_i, hence convex. Second, the logarithm of the sum is also convex - since $\ln \alpha_{ik} x_{ik}^{\rho_i} = \ln \alpha_{ik} + \rho_i \ln x_{ik}$ is convex and the sum of log-convex functions is log convex. Finally this convex expression is multiplied by a negative constant $1/\rho_i$ so it is concave. When $\rho_i = 0$ the first term in (5) is Cobb-Douglas, which is concave for the values of α specified. This establishes the concavity of the first term. Clearly the second term in (5) is a convex function of x_i and hence the negative of the second term is concave. The sum of two concave functions being concave, we conclude that $U_i(\mathbf{x})$ is a concave function of x_i (indeed, it is strictly concave). Now consider the n-player game in which the payoff function to each player i is $\pi_i(\mathbf{x}) = e^{U_i(\mathbf{x})}$. Since this is a continuous and strictly increasing function of i's utility function, the set of (pure strategy) Nash equilibria in the so-defined game is identical with the set of population equilibria. Moreover, in this game, each player's strategy set, $B(p, Y_i)$, is nonempty, compact and convex and π_i is a continuous payoff function (with domain $\times_{j \in I} B(p, Y_j)$). Hence, by Weierstrass' maximum theorem, each player's best-reply correspondence is nonempty-valued and compact-valued, and, by Berge's maximum theorem, upper hemi-continuous. In order to apply Kakutani's fixed-

[55] $u_i(x_i) > \min\{u_i(x_i^*), u_i(x_i^o)\} = u_i(x_i^*)$.

point theorem it only remains to verify that each best-reply correspondence is also convex-valued. But this follows from the concavity of U_i with respect to x_i, which implies that π_i is quasi-concave in x_i. To see this, let $\alpha > 0$ and fix $\mathbf{x}^o_{-i}$. Then $\pi_i\left(x_i, \mathbf{x}^o_{-i}\right) \geq \alpha$ is equivalent to $U_i\left(x_i, \mathbf{x}^o_{-i}\right) \geq \beta = \ln \alpha$, which defines a convex subset of $B\left(p, Y_i\right)$ by concavity of $U_i\left(x_i, \mathbf{x}^o_{-i}\right)$ with respect to x_i. Moreover, $\pi_i\left(\mathbf{x}\right) \geq 0$ is equivalent to $x_i \in B\left(p, Y_i\right)$, again a convex set. Hence the game with payoff functions π_i admits at least one Nash equilibrium, by Kakutani's theorem. That each equilibrium is interior follows from the observation made before the statement of the proposition.

10.3. Proof of Proposition 4. Consider the first-order condition (10). We know an interior solution exists and is unique, $x^*_{i1} \in (0, y_i/p)$, for each $\rho_i < 1$. The first-order condition can be rewritten as

$$\frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{y_i - px^*_{i1}}{x^*_{i1}}\right)^{1-\rho_i} - p + \frac{\beta_i\sigma_i\theta_{i1}(\theta_{i1}x^*_{i1} - \varepsilon_i - \mu_i)}{1 - \beta_i\sigma_i\theta_{i1}(\theta_{i1}x^*_{i1} - \varepsilon_i - \mu_i)x^*_{i1}} \cdot y_i = 0.$$

The left-hand side is decreasing in x_{i1}. It follows that if the left-hand side is increasing in y_i, then x^*_{i1} will be increasing in y_i. If the left-hand side were instead decreasing in y_i, then x^*_{i1} would be decreasing in y_i. We can denote the derivative of the left-hand side with respect to y_i as D_{ρ_i}, where:

$$D_{\rho_i} = (1 - \rho_i)\frac{\alpha_{i1}}{\alpha_{i2}}\frac{1}{x^*_{i1}}\left(\frac{y_i - px^*_{i1}}{x^*_{i1}}\right)^{-\rho_i} - \frac{\beta_i\sigma_i\theta_{i1}(\theta_{i1}x^*_{i1} - c_i - \mu_i)}{1 - \beta_i\sigma_i\theta_{i1}(\theta_{i1}x^*_{i1} - c_i - \mu_i)x^*_{i1}}.$$

First consider the case $\rho_i \leq 0$. Rewrite the first-order condition (10) as

$$\begin{aligned} 0 = {} & y_i\left[\frac{\alpha_{i1}}{\alpha_{i2}}\frac{1}{x^*_{i1}}\left(\frac{y_i - px^*_{i1}}{x^*_{i1}}\right)^{-\rho_i} - \frac{\beta_i\sigma_i\theta_{i1}(\theta_{i1}x^*_{i1} - c_i - \mu_i)}{1 - \beta_i\sigma_i\theta_{i1}(\theta_{i1}x^*_{i1} - c_i - \mu_i)x^*_{i1}}\right] \\ & -p\left[1 + \frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{y_i - px^*_{i1}}{x^*_{i1}}\right)^{-\rho_i}\right] \end{aligned}$$

Since the second term in this expression is negative, the first term must be positive. It then follows that $D_{\rho_i} > 0$ (since $1 - \rho_i \geq 1$). Thus x^*_{i1} is increasing in y_i when $\rho_i \leq 0$.

Second we consider the case $\rho_i > 0$ and rewrite

$$x^*_{i1}D_{\rho_i} = (1 - \rho_i)\frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{y_i - px^*_{i1}}{x^*_{i1}}\right)^{-\rho_i} - \frac{\beta_i\sigma_i\theta_{i1}(\theta_{i1}x^*_{i1} - c_i - \mu_i)x^*_{i1}}{1 - \beta_i\sigma_i\theta_{i1}(\theta_{i1}x^*_{i1} - c_i - \mu_i)x^*_{i1}} \quad (15)$$

Since $x_{i1}^{*}>0$ for all $y_i>0$ the sign of D_{ρ_i} is the same as the sign of the left hand side of (15). From the first-order condition (10) we note that as $y_i \to \infty$ the term $\left(\frac{y_i-px_{i1}^{*}}{x_{i1}^{*}}\right)^{-\rho_i}$ is continuously decreasing and tends to zero for all $\rho_i>0$.[56] The second term on the right hand side of (15) is greater than $\frac{\beta_i\sigma_i\theta_{i1}(\theta_{i1}x_{i1}'-c_i-\mu_i)x_{i1}'}{1-\beta_i\sigma_i\theta_{i1}(\theta_{i1}x_{i1}'-c_i-\mu_i)x_{i1}'}$ (where this is strictly positive) where $\phi\left(x_{i1}'\right)=\mu_i$ for y_i large enough. It follows that $D_{\rho_i}<0$ for y_i large enough.

Finally we show that x_{i1}^{*} is decreasing in y_i for all $y_i \geq \hat{y}_i$ for some $\hat{y}_i$. Rewrite the first order condition

$$
\begin{aligned}
&(1-\rho_i)\,\frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{y_i-px_{i1}^{*}}{x_{i1}^{*}}\right)^{-\rho_i}-\frac{\beta_i\sigma_i\theta_{i1}(\theta_{i1}x_{i1}^{*}-c_i-\mu_i)x_{i1}^{*}}{1-\beta_i\sigma_i\theta_{i1}(\theta_{i1}x_{i1}^{*}-c_i-\mu_i)x_{i1}^{*}}\\
=\;&\frac{px_{i1}^{*}}{y_i}+\left(\frac{px_{i1}^{*}}{y_i}-\rho_i\right)\frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{y_i-p_1x_{i1}^{*}}{p_2x_{i1}^{*}}\right)^{-\rho_i}
\end{aligned}
$$

The right hand side is decreasing in y_i since px_{i1}^{*}/y_i must be non-increasing in y_i,[57] and $\left(\left(y_i-px_{i1}^{*}\right)/x_{i1}^{*}\right)^{-\rho_i}$ is decreasing in y_i. It follows that $x_{i1}^{*}D_{\rho_i}$ is decreasing in y_i and so D_{ρ_i} is negative at some $\hat{y}_i$ and remains negative for all $y_i \geq \hat{y}_i$.

10.4. Parameter Estimates. Ideal BMI is set at 22.5, approximately the middle of the range of medically normal BMI. The parameters for the metabolism function $w_i=\theta_i\cdot x_{1i}-\varepsilon_i$ are estimated as $\theta_1=1.3$ and $\varepsilon=12.35$ for men and women combined, where x_{1i} is measured in hundreds of calories and gives the daily caloric intake that leads to an equilibrium BMI of w_i. This is derived from previous work and biology literature as follows. Cutler et al. (2003) estimate a weight equation in the form $weight_{kg}=(0.9\times calories-a)/b+E$ where $E\approx 14$, $a=879$ and $b=11.6$ for men, and $a=829$ and $b=8.7$ for women (Schofield, 1985). Rewriting this in terms of BMI rather than weight in kilos, we have

$$
BMI=\frac{weight_{kg}}{height_m^2}=\frac{1}{height_m^2}\frac{0.9\times 100\times calories_{hundreds}-a}{b+E}.
$$

We estimate mean height of men to be 1.77 meters and mean height of women to be 1.63 meters and for simplicity will assume these heights for the whole pop-

[56] If x_{i1}^{*} is decreasing in y_i this is clearly true. If x_{i1}^{*} is increasing in y_i then the term $\frac{\beta_i\sigma_i\theta_{i1}(\theta_{i1}x_{i1}^{*}-\varepsilon_i-\mu_i)}{1-\beta_i\sigma_i\theta_{i1}(\theta_{i1}x_{i1}^{*}-\varepsilon_i-\mu_i)x_{i1}^{*}}\cdot y_i \to \infty$ as $y_i\to\infty$, and so $\frac{\alpha_{i1}}{\alpha_{i2}}\left(\frac{y_i-px_{i1}^{*}}{x_{i1}^{*}}\right)^{1-\rho_i}$ also tends to ∞ as $y_i\to\infty$ for the first order condition to hold. It follows that $\frac{y_i-px_{i1}^{*}}{x_{i1}^{*}}$ tends to ∞ as $y_i\to\infty$.

[57] This follows from the result that $\frac{y_i-px_{i1}^{*}}{x_{i1}^{*}}$ is increasing in y_i. Multiplying the numerator and denominator by x_{i1}^{*}, $\frac{y_i-px_{i1}^{*}}{x_{i1}^{*}}$ can be rewritten as $y_i/x_{i1}^{*}-p$.

ulation. The relative price of weight-enhancing food is estimated to be $p = 80$. This comes from noting that an individual with income in the bracket whose midpoint is \$7500 has mean BMI of 29.8 so must purchase a caloric intake of $x_{i1} = 32.4$. From the US Consumer Expenditure Survey (CES) 1999, an individual with income of \$7,500 spends approximately 35% on food (excluding lean meat, fish, fruit and vegetables) and 65% on other non durables including apparel and services, entertainment, housekeeping supplies, personal care products, reading, tobacco, miscellaneous, lean meat, fish, fruit and vegetables. Thus $p_1 \approx (0.35 \times 7500)/32.4$. We do not need to estimate p_2 since the first order condition can be written as

$$\frac{\alpha_1}{\alpha_2} p_2^{\rho} \left(\frac{Y_i - p_1 x_{i1}}{x_{i1}} \right)^{1-\rho_i} = p_1 + \frac{\beta\sigma\theta_{i1}(\theta_{i1}x_{i1} - \varepsilon - \mu)Y_i}{1 - \beta\sigma\theta_1(\theta_1 x_{i1} - \varepsilon - \mu)x_{i1}}$$

and so p_2 is incorporated into the parameter α, with $\alpha = \alpha_{i1} p_2^{\rho} / \alpha_{i2}$, and we set $y_i = Y_i$ and $p = p_1$. Finally we estimate $\alpha = 14.36$, $\beta\sigma = 0.00084$, $\rho = 0.53$. These three parameters are chosen to fit the NHANES data on BMI and income given the other parameter estimates.

References

[1] Auld, M.C. and N. Sidhu (2005): "Schooling, cognitive ability and health", *Econometrics and Health Economics* 14, 1019-34.

[2] Banerjee, A. and S. Mullainathan (2010): "The shape of temptation: Implications for the economic lives of the poor" NBER working paper 15973.

[3] Barro, R.J. (1999): "Ramsey meets Laibson in the neoclassical growth model", *Quarterly Journal of Economics* 114, 1125–52.

[4] Bernheim, B.D. (1994): "A theory of conformity", *Journal of Political Economy* 102, 841-77.

[5] Berrington de Gonzalez, A., P. Hartge, J.R. Cerhan, A.J. Flint, L. Hannan, R.J. MacInnis et al. (2010): "Body-mass index and mortality among 1.46 million white adults", *New England Journal of Medicine* 363, 2211–19.

[6] Blanchflower, D. G., A. J. Oswald and B. Van Landeghem (2009): "Imitative obesity and relative utility", *Journal of the European Economic Association* 7, 528-38.

[7] Burke, M. A. and F. W. Heiland (2006): "The Strength of Social Interactions and Obesity Among Women", in F. Billari, T. Fent, A. Prskawetz, and J. Scheffran, eds., Agent-Based Computational Modelling. Heidelberg: Physica Verlag.

[8] Burke, M. A. and F. W. Heiland (2007): "Social dynamics of obesity", *Economic Inquiry* 45, 571-91.

[9] Burke, M. A., F. W. Heiland and C. M. Nadler (2010): "From 'overweight' to 'about right': evidence of a generational shift in body weight norms", *Obesity* 18, 1226-34.

[10] Carmalt, J. H., J. Cawley, K. Joyner and J. Sobal (2008) "Bodyweight and matching with a physically attractive romantic partner" *Journal of Marraige and Family* 70, 1287-96.

[11] Cawley, J. (2004): "The impact of obesity on wages", *Journal of Human Resources* 39, 451-74.

[12] Chang, V.W. and D.S. Lauderdale (2005): "Income disparities in body mass index and obesity in the United States, 1971-2002", *Archives Internal Medicine* 165, 2122-2128.

[13] Chou, S., M. Grossman and H. Saffer (2004): "An economic analysis of adult obesity: results from the Behavioral Risk Factor Surveillance System.", *Journal of Health Economics* 23, 565-87.

[14] Christakis, N.A. and J.H. Fowler (2007): "The spread of obesity in a large social network over 32 years", *New England Journal of Medicine* 357, 370-79.

[15] Cohen-Cole, E. and J. M. Fletcher (2008): "Detecting implausible social network effects in acne, height, and headaches: longitudinal analysis" *BMJ* 337:a2533.

[16] Costa, D. and R. Steckel (1997): "Long-term trends in health, welfare and economic growth in the United States." In R. Floud and R. Steckel (Eds.) *Health and welfare during industrialization*. Chicago: University of Chicago Press for National Bureau of Economic Research.

[17] Cutler, D.M., E.L. Glaeser and J.M. Shapiro (2003): "Why have Americans become more obese?", *Journal of Economic Perspectives* 17, 93-118.

[18] Cutler, D.M. and A. Lleras-Muney (2010): "Understanding differences in health behaviors by education", *Journal of Health Economics* 29, 1-28.

[19] Dragone, D. (2009): "A rational eating model of binges, diets and obesity", *Journal of Health Economics* 28, 799-804.

[20] Dragone, D. and L. Savorelli (2012): "Thinness and obesity: A model of food consumption, health concerns, and social pressure", *Journal of Health Economics* 31, 243-256.

[21] Dubois, P., R. Griffith and A. Nevo (2012): "Do Prices and Attributes Explain International Differences in Food Purchases?", mimeo.

[22] Finkelstein, E.A., C. J. Ruhm, and K. M. Kosa (2005): "Economic causes and consequences of obesity", *Annual Review of Public Health* 26, 239-57.

[23] Finkelstein, E.A., J.G. Trogdon, J.W. Cohen, and W. Dietz (2009): "Annual medical spending attributable to obesity: payer- and service-specific estimates", *Health Affairs* 28, 822-31.

[24] Flegal, K.M., M.D. Carroll, C.L. Ogden and C.L. Johnson (2002): "Prevalence and trends in obesity among US Adults, 1999-2000", *Journal of the American Medical Association* 288, 1723-27.

[25] Flegal, K.M., M.D. Carroll, C.L. Ogden and L.R. Curtin (2010): "Prevalence and trends in obesity among US Adults, 1999-2008", *Journal of the American Medical Association* 303, 235-41.

[26] Fogel, R.W. (1994): "Economic growth, population theory and physiology: The bearing of long-term processes on the making of economic policy", *American Economic Review* 84, 369-95.

[27] Gelbach, J.B., J. Klick and T. Stratmann (2009): "Cheap donuts and expensive broccoli: the effect of relative prices on obesity", Working paper. Florida State Univeristy.

[28] Glaeser, E. and J. A. Scheinkman (2000): "Non-market interactions", NBER working paper 8053.

[29] Goldman, D. P. and J.P. Smith (2002): "Can patient self-management help explain the SES health gradient?", *PNAS* 99 10929-34.

[30] Grossman, M. (1972): "On the concept of health capital and the demand for health", *Journal of Political Economy* 80, 223-55.

[31] Hall, R.E. and C.I. Jones (2007): "The value of life and the rise in health spending", *Quarterly Journal of Economics* 122, 39-72.

[32] Hall, K.D., G. Sacks, D. Chandramohan, C. C. Chow, Y. C. Wang, S. L. Gortmaker and B. A. Swinburn (2011): "Quantification of the effect of energy imbalance on bodyweight", Lancet 378, 826–37.

[33] Heckman, J. J. and T. D Kautz (2012): "Hard evidence on soft skills", NBER working paper 18121.

[34] Komlos, J and M Brabec (2011): "The trend of BMI values of US adults by deciles, birth cohorts 1882–1986 stratified by gender and ethnicity", *Economics and Human Biology* 9, 234–50.

[35] Lakdawalla, D., T. Philipson and J. Bhattacharya (2005): "Welfare-enhancing technological change and the growth of obesity", *American Economic Review* 95, 253-57.

[36] Lakdawalla, D. and T. Philipson (2009): "The growth of obesity and technological change", *Economics and Human Biology* 7, 283–93.

[37] Lindbeck, A., S. Nyberg and J. Weibull (1999): "Social norms and economic incentives in the welfare state", *Quarterly Journal of Economics* 114, 1-35.

[38] Lindbeck, A., S. Nyberg and J. Weibull (2003): "Social norms and welfare state dynamics", *Journal of the European Economic Association* 1, 533-42.

[39] Ljungvall, A. and F. J. Zimmerman (2012): "Bigger bodies: Long-term trends and disparities in obesity and body-mass index among U.S. adults, 1960-2008" *Social Science & Medicine* 75, 109-19.

[40] Mazzocchi, M., W. B. Traill and J. F. Shogren (2009): "Fat economics: nutrition, health and economic policy", Oxford University Press.

[41] McLaren, L. (2007): "Socioeconomic status and obesity", *Epidemiologic Reviews* 29, 29-48.

[42] McPherson, M., L. Smith-Lovin and J. M. Cook (2001): "Birds of a feather: homophily in social networks", *Annual Review of Sociology* 27, 415-44.

[43] Muennig, P., H. Jia, R. Lee and E. Lubetkin (2008): "I Think Therefore I Am: Perceived Ideal Weight as a Determinant of Health", *American Journal of Public Health* 98, 501–6.

[44] O'Donoghue, T. and M. Rabin (1999): "Doing it now or later", *American Economic Review* 89, 103-24.

[45] Offer, A., R. Pechey and S. Ulijasek (2010): "Obesity under affluence varies by welfare regimes: The effect of fast food, insecurity, and inequality", *Economics and Human Biology* 8, 297-308.

[46] Oswald, A. J. and N. Powdthavee (2007): "Obesity, unhappiness, and the challenge of affluence: theory and evidence" *Economic Journal* 117, 441-54.

[47] Pieroni, L., D. Lanari and L. Salmasi (2011): "Food prices and overweight patterns in Italy", *European Journal of Health Economics*, 1–19. 10.1007/s10198-011-0350-y.

[48] Prospective Studies Collaboration (2009): "Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies", *Lancet* 373, 1083–96.

[49] Rand, C. S. W. and J. L. Resnick (2000): "The 'good enough' body size as judged by people of varying age and weight", *Obesity Research* 8, 309-16.

[50] Renna, F., I. B. Grafova and N. Thakur (2008): "The effect of friends on adolescent body weight", *Economics and Human Biology* 6, 377–87.

[51] Ravussin, E. and C. Bogardus (1989): "Relationship of genetics, age, and physical fitness to daily expenditure and fuel utilization", *American Journal of Clinical Nutrition* 49, 968-75.

[52] Schofield, W.N. (1985): "Predicting basal metabolic rate, new standards and review of previous work", *Human Nutrition: Clinical Nutrition* 39, 5-41.

[53] Shapiro, J.M. (2005): "Is there a daily discount rate? Evidence from the food stamp nutrition cycle", *Journal of Public Economics*. 89, 303-25.

[54] Swinburn, B. A., G. Sacks, K. D. Hall, K. McPherson, D. T. Finegood, M. L. Moodie and S. L. Gortmaker (2011): "The global obesity pandemic: shaped by global drivers and local environments", *Lancet* 378, 804-14.

[55] Trogden, J.G., J. Nonnemaker and J. Pais (2008): "Peer effects in adolescent overweight", *Journal of Health Economics* 27, 1388-99.

[56] Wang, Y. C, K. McPherson, T. Marsh, S. L. Gortmaker and M. Brown (2011) "Health and economic burden of the projected obesity trends in the USA and the UK", *Lancet*, 378, 815–25.

[57] Zheng, X. and C. Zhen (2008): "Healthy food, unhealthy food and obesity", *Economics Letters* 100, 300-3.