A Mass Phenomenon: The Social Evolution of Obesity

Holger Strulik*

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Abstract. This paper proposes a theory for the social evolution of obesity. It considers a society, in which individuals experience utility from consumption of food and non-food, the state of their health, and the evaluation of their appearance by others. The theory explains why, ceteris paribus, poor persons are more prone to be severely overweight although eating is expensive and how obesity occurs as a social phenomenon such that body mass continues to rise long after the initial cause (e.g. a lower price of food) is gone. The paper investigates the determinants of a steady-state at which the median citizen is overweight and how an originally lean society arrives at such a steady-state. Extensions of the theory towards dietary choice and the possibility to exercise in order to loose weight demonstrate robustness of the basic mechanism and provide further interesting results.

Keywords: Obesity Epidemic, Social Dynamics, Social Multiplier, Income Gradient, Feeling Fat, Feeling Unhealthy, Fat Tax.

JEL: D11, I14, Z13.

* University of Hannover, Wirtschaftswissenschaftliche Fakultaet, 30167 Hannover, Germany; email: strulik@vwl.uni-hannover.de.

1. Introduction

Since about the last quarter of the 20th century we witness an unprecedented change in the phenotype of human beings. In the US, for example, the share of overweight (obese) persons was almost constant at about 45 percent (15 percent) of the population in the years 1960 to 1980. Since then, the share of overweight adults rose to 64.7 in the year 2008 and the share of obese adults rose to 34.3 (Ogden and Carroll, 2010). If these trends continue, by 2030, 86 percent are predicted to be overweight and 51 percent to be obese (Wang et al., 2008).[1] The phenomenon of increasing waistlines is particularly prevalent in the US but, in principle, observed globally (OECD, 2010, WHO, 2011). The world is getting fat (Popkin, 2009).

Obesity entails substantial health costs. Obese persons are more likely to suffer from diabetes, cardiovascular disease, hypertension, stroke, various types of cancer and many other diseases (Field et al., 2001, Flegal et al., 2005). As a consequence, obese persons do not only spend more time and money on health care (Finkelstein et al., 2005, OECD, 2010) but they also pass away earlier. For example, compared to their lean counterparts, 20 year old US Americans can expect to die about four years earlier when their bmi exceed 35 and about 13 years earlier when their bmi exceeds 45 (Fontaine et al., 2003). According to one study, obese persons actually incur lower health care costs over their life time due to their early expiry (van Baal et al., 2008).

The simple answer for why people are overweight is that they like to eat more than their body can burn. In the US, for example, 70 percent of the adult population in the year 2000 said that they eat "pretty much whatever they want"(USDA, 2001). Although a fully satisfying answer is certainly more complex, involving biological and psychological mechanisms, the perhaps most striking observation in this context is that overeating seems *not* to be driven by affluence. At the beginning of the 20th century, when the developed countries were certainly no longer constrained by subsistence income the English physiologist W.M. Bayliss wrote

[1]Overweight is defined as a body mass index (bmi) above 25 and obesity as a bmi above 30. In this paper we thus apply the inclusive definition of overweight by the WHO (2011), according to which obese persons are also regarded as overweight. Some other studies apply an exclusive definition according to which only persons with bmi between 25 and 30 are regarded as overweight. The bmi is defined as weight in kilogram divided by the square of height in meters.

that "it may be taken for granted that every one is sincerely desirous of avoiding unnecessary consumption of food" (Bayliss, p. 1). Indeed, caloric intake per person in the US remained roughly constant between 1910 and 1985. But it then rose by 20% between 1985 and 2000 (Putnum et al., 2002, see also Cutler et al., 2003 and Bleich et al., 2008).

Across the population, within countries, the historical association between affluence and body mass actually changed its sign over the 20th century; "where once the rich were fat and the poor were thin, in developed countries these patterns are now reversed." (Pickett et al., 2005). But while it is true that the *severity* of overweight and obesity is much stronger for the poor than for the non-poor (Joliffe, 2011), it is also true that persons from all social strata are equally likely to be overweight (in the US) and that the secular *increase* of overeating and overweight is equally observed among – presumambly richer – college graduates and non-college educated persons (Ruhm, 2010). Across countries, obesity and calorie consumption appear to be more prevalent in unequal societies (Pickett et al, 2005).

The evolving new human phenotype cannot be explained by genetics because it occurred too rapidly (e.g. Philipson and Posner, 2008). It has to be conceptualized as a social phenomenon. With affluence being an unlikely candidate, the question occurs what has caused the social evolution of overweight and obesity. The most popular factors suggested in the literature are decreasing food prices, decreasing *effective* food prices through readily available convenience foods and restaurant supply, and less physical activity on the job and in the household (see e.g. Finkelstein et al., 2005, OECD, 2010). But these explanations entail some unresolved puzzles with respect to the timing of the obesity epidemic.

The most drastic changes of potential causes of obesity occurred well before obesity prevalence became a mass phenomenon. The price of food declined substantially from the early 1970s through the mid 1980s but changed little thereafter, when the obesity epidemic took off. Eating time declined substantially from the late 1960s to the early 1990s, but stabilized thereafter (see Ruhm, 2010). Likewise, the gradual decline in manual labor and the rise of labor saving technologies at home began before the rapid rise in obesity and slowed down afterwards (Finkelstein et al., 2005). This means that calories expended have not decreased much further since 1980s (Cutler et al., 2003).

From these facts some studies conclude that food prices and caloric expenditure are unlikely to be major contributors to the evolution of obesity because the prevalence of obesity continues to rise after the alleged causes have (almost) disappeared. The present paper proposes an alternative conclusion based on social dynamics. It explicitly considers that one's appearance is evaluated by others according to an evolving social norm. The norm for displaying a lean body is continuously (but slowly) updated by the actual observation of the prevalence of overweight in society. This view provides (i) a social multiplier that amplifies the "impact effect" of exogenous shocks, and (ii) an explanation for why we observe an evolving human phenotype long after the impact effect is gone.

The theory establishes two exclusively existing, stable, and qualitatively distinct social equilibria. At one equilibrium the median citizen is lean and after an exogenous shock that favors overeating (e.g. lower food prices) social pressure leads society back to the lean equilibrium. This means that, although there are overweight and obese persons in society, obesity is not an evolving social problem. At the other equilibrium the median is overweight and after an exogenous shock that favors overeating, society at large converges towards an equilibrium where people are, on average, heavier than before. The historical evolution of bmi in the US., for example, is conceptualized according to the theory as a stable lean steady-state until the 1970s and a transition towards a stable obese steady-state afterwards.

The theory explicitly takes into account that preferences and income vary across individuals. Holding income constant it predicts that people with a high preference for food consumption are heavier. Holding preferences constant it predicts that poorer people are heavier. The reason is that utility is non-separable. A rich person inevitably consumes more (food or non-food) than a poor one. Given non-separable utility, she thus experiences higher marginal utility from being lean (or less overweight). Consequently, she consumes less calories. A poor person, with contrast, puts less emphasis on the evaluation of her appearance by others and on the health consequences of being overweight because the scale of consumption (food or non-food) is low. Due to the lower emphasis on weight a larger share of experienced utility results from food consumption, in particular if food prices are low compared to other goods. Since the median is poorer in unequal societies, the theory predicts, that, ceteris paribus, unequal societies are more afflicted by the obesity epidemic.

In Section 3 it is shown that the social multiplier produces some, perhaps unexpected, non-linearities. In particular, an obesity related health innovation (e.g. beta-blockers, dialysis) can go awry. The impact effect of such an innovation is clearly better health for everybody. But lower health consequences of being overweight induces some people to eat more and put on more weight. This may set in motion a bandwagon effect and convergence towards a new steady-state at which society is, on average, not only heavier but also less healthy than before the health innovation.

The basic model fails to capture some further aspects of the obesity epidemic, most importantly the role of energy-density of food and that of physical exercise. Section 4 thus extends the model to account for these factors and shows that all basic results are preserved under mild conditions. It also derives some refinements of the original theory. For example, while richer people, continue to be predicted to be, ceteris paribus, less overweight, leaner bodies are no longer necessarily a consequence of eating less. Instead, richer people are predicted to exercise more for weight loss. In a two-diet model, a rising energy density of the less healthy diet is predicted to increase body mass if the diet is sufficiently cheap and its consumer sufficiently poor. If this applies to the median citizen, society at large is predicted to get heavier due to the social multiplier.

There exists some evidence supporting the basic assumption that being overweight generates less disutility if many others are overweight or obese as well, that is if the prevalence of overweight in society is high. Blanchflower et al. (2009) find that females across countries are less dissatisfied with their actual weight when it is *relatively* low compared to average weight. Using the German Socioeconomic Panel they furthermore find that males, controlling for their actual weight, experience higher life satisfaction when their relative weight is lower. In the US, about half of respondents to the Pew Review (2006) who are classified as overweight according to the official definition characterize their own weight as "just about right". Etilé (2007) provides similar results for France and argues that social norms and habitual bmi affect ideal bmi, which in turn influences actual bmi. Christakis and Fowler (2007) show how obesity spreads from person to person in a large social network and find that a person's chances to become overweight increase by 57 percent if he or she has a friend who became obese. Trogdon et al. (2008) find that for US adolescents in 1994-5 individual bmi was correlated with mean peer bmi and that the probability of being overweight was correlated with the proportion of overweight peers. Nevertheless, using the methodology of Glaeser et al. (2003), Auld (2011) finds only small contemporaneous social multipliers for bmi at the county and state level in the US in 1997-2002. Since the method focusses on contemporaneous interaction, it provides indirect support for a dynamic process of a slowly evolving social norm (gradually decreasing social disapproval of overweight).

There exists a by now large literature of economic theories on obesity but social interaction is mostly neglected.[2] Some empirical studies on obesity and social interaction are motivated with rudimentary models (Etilé, 2007, Blanchflower et al., 2008). Burke and Heiland (2007) propose a model of social dynamics of obesity, which – like the present study – emphasizes the role of a social multiplier in the gradual amplification of obesity prevalence. The solution method, however, is purely numerical; there are no general results, derived analytically. Wirl and Feichtinger (2010) propose a mathematically more involved model in a similar spirit. Both studies, furthermore, do not consider a heterogenous society stratified by income. The present study tries to prove as many results as possible analytically and explicitly considers idiosyncratic differences in preferences and income. Moreover, extensions of the basic model demonstrate robustness of results with respect to dietary choice and physical exercise, factors, which have not been addressed in this context so far. The present study thus proposes a

[2]For a survey see Rosin (2008); see also the extensive discussion in Cutler et al. (2003), Lakdawalla et al. (2005), and Philipson and Posner (2009). The economic literature on social norms, based on Granovetter (1978) and Bernheim (1994), has already provided important insight into other phenomena, including the growing welfare state (Lindbeck, et al., 1999), out-of-wedlock childbearing (Nechyba, 2001), family size (Palivos, 2001), women's labor force participation (Hazan and Maoz, 2002), occupational choice (Mani and Mullin, 2004), contraceptive use (Munshi and Myaux, 2006), work effort (Lindbeck and Nyberg, 2006), cooperation in prisoner's dilemmas (Tabellini, 2008), and education (Strulik, 2012).

theory that is suitable to explain the socio-economic gradient of obesity and to provide a comprehensive understanding of the social evolution of obesity.

2. The Model

2.1. **Setup of Society.** Consider a society consisting of a continuum of individuals of fixed height, which is for simplicity normalized to unity, implying that weight equals bmi. Later on, in the numerical part of the paper the normalization allows for an easy comparison of results with actual data on obesity. Individuals experience utility from food consumption and from consumption of other goods. Consumption of food ("victuals") of individual i in period t is denoted by $v_t(i)$ and other consumption is denoted by $c_t(i)$. The relative price of food is given by p_t. Each individual faces a given income $y(i)$ and thus the budget constraint (1).

$$y(i) = c_t(i) + p_t v_t(i). \tag{1}$$

We allow income to be individual-specific but keep it constant over time in order to focus on social dynamics.

Units of food are converted into units of energy by the energy exchange rate ϵ such that individual i consumes $\epsilon v_t(i)$ energy units in period t. For simplicity we assume that the period length is long enough – say, a month – such that we can safely ignore the specific (thermo-) dynamics of how energy consumption relates to energy expenditure and fat cell generation and growth. Instead we assume that there exists an ideal consumption of energy per period $\mu(i)$ such that any consumption beyond it translates one-to-one into excess weight. Specifically, overweight of individual i in period t is given by (2).

$$o_t(i) = \epsilon v_t - \mu(i) \geq 0. \tag{2}$$

In order to simplify the algebra we impose the constraint that $o_t(i) \geq 0$. This condition, reminiscent of the subsistence constraint in macroeconomics, avoids to impose specific health and social costs from consuming less energy than required to sustain a healthy body and to consider explicitly that some people in society prefer to be underweight. It helps to focus on the obesity problem. “Subsistence needs” $\mu(i)$ can be thought of as individual specific (and potentially occupation-dependent) metabolic needs of a lean body.

In the basic model, in which there exists just one type of food, all individuals face the same energy exchange rate. Section 4 sets up an extension with two types of diets for which different prices and energy exchange rates apply (junk food and healthy food). This allows to optimize over the selection of a specific diet. It will be shown that all results from the basic model, in which individuals can only choose the quantity but not the quality of their food, hold true in the extended version as well.

Being overweight causes health costs and social costs, which are both assumed to increase in excess weight. Health costs per unit of excess weight, η, are treated parametrically, which provides an interesting experiment of comparative statics with respect to medical technological progress. The arrival of beta blockers, for example, can be thought of as a reduction of η. The social cost of being overweight s_t, on the other hand, is explicitly treated as a variable in order to address social dynamics. The presence of health costs and social costs diminishes utility from consumption. Specifically, we assume that utility of individual i in period t is given by

$$U_t(i) = [c_t(i) + \beta(i)v_t(i)]^{\alpha} \cdot [1 - (s_t + \eta)o_t(i)]^{1-\alpha}. \tag{3}$$

Here, α measures the importance of consumption for utility relative to the consequences of food consumption on health and social approval. The parameters $\beta(i)$ capture the preference for food consumption vs. non-food consumption. In order to arrive at an explicit solution, utility from consumption has been assumed to be of the so called Greenwood-Hercowitz-Huffman (1988) type. It will become evident below that, qualitatively, results are not driven by this assumption. The non-separability of utility, on the other hand, will be crucial of the results with respect to income. In simple words non-separability means that, ceteris paribus, less overweight persons experience more utility from consumption – be it in form of food (another burger) or non-food (a sunbath at the pool).

The parameter $\beta(i)$ measures how pleasurable food consumption is compared to other consumption. It can be thought of as a compound consisting of a common term β and an idiosyncratic term $\hat{\beta}(i)$, that is $\beta(i) \equiv \beta \cdot \hat{\beta}(i)$. Whereas $\hat{\beta}(i)$ measures the "sweet tooth" of person i, the common component β allows for another interesting comparative static with respect to food processing technology that manipulates the general desirability of food (for example, flavor enhancing technologies).

The time cost of food preparation, which is frequently discussed in the literature as a cause of increasing obesity, is not explicitly modeled. In reduced form, lower time costs of food preparation can be thought of reduced effective price p of food. Moreover, lower food preparation time may increase the pleasure of eating, which would be captured by an increase of the common preference parameter β.

Individual self-control problems, although not explicitly modeled, can be thought of as being captured by the idiosyncratic preference parameter $\hat{\beta}(i)$. Persons with a dominant affective system experience more gratification from food consumption (above metabolic needs) and display a larger $\hat{\beta}(i)$ compared to more deliberate persons. A detailed understanding of how *psychological* and *technological* mechanisms affect obesity is certainly useful and it has been advanced within an economic framework elsewhere (e.g. Cutler, 2003, Philipson and Posner, 2003, Ruhm, 2010). Lumping these aspects together in one compound parameter is only justified by the focus for the present study, which is neither on psychological nor on technological aspects but on the *social* mechanisms of obesity.

2.2. **Individual Utility Maximization.** Any individual i is assumed to maximize utility (3) subject to the budget constraint (1) and the weight constraint (2). The first order condition for an interior solution requires that

$$\alpha(\beta(i) - p_t)\left[y(i) + (\beta(i) - p_t)v_t(i)\right]^{\alpha-1} \cdot \left[1 - (s_t + \eta)(\epsilon v_t(i) - \mu(i))\right]^{1-\alpha} =$$
$$\epsilon(s_t + \eta)(1 - \alpha)\left[y(i) + (\beta(i) - p_t)v_t(i)\right]^{\alpha} \cdot \left[1 - (s_t + \eta)(\epsilon v_t(i) - \mu(i))\right]^{-\alpha}.$$

Marginal utility from food consumption, at the left hand side of the equation, is required to equal marginal disutility from the consequences of food consumption on overweight, at the right hand side. For better interpretation the condition can be simplified by monotonous transformations to (4).

$$\alpha \cdot [\beta(i) - p_t] \cdot \{1 - (s_t + \eta)(\epsilon v_t(i) - \mu(i))\} = \epsilon \cdot (s_t + \eta) \cdot (1 - \alpha) \{y(i) + [\beta(i) - p_t] v_t(i)\}. \tag{4}$$

The left hand side of the optimality condition has been transformed to a positive *measure* of marginal utility from food consumption and the right hand side of (4) measures marginal disutility from the consequence of food consumption on overweight. A necessary, not sufficient condition for excess food consumption is $\beta(i) > p_t$. To see this, note that both terms in in curly parenthesis in (4) have to be strictly positive for positive utility. The result is intuitive. Because the price of non-food has been normalized to one, it means that for excess food consumption to occur, food consumption has to provide higher utility than non food consumption ($\beta(i) > 1$), or the price of food has to be lower than the price of non-food ($p_t < 1$), or both. Otherwise, the non-negativity constraint binds and individuals derive pleasure from eating only until their ideal metabolic needs are fulfilled, $\epsilon v_t(i) = \mu(i)$. This means that for overweight to be an observable phenomenon, $\beta(i) > p_t$ has to hold for at least some individuals in society.

The solution of (4) provides optimal excess food consumption of person i in period t:

$$v_t(i) = \frac{\alpha[\beta(i) - p_t] - (s_t + \eta) \{(1 - \alpha)\epsilon y(i) - \alpha[\beta(i) - p_t]\mu(i)\}}{\epsilon(s_t + \eta)[\beta(i) - p_t]}. \tag{5}$$

Together with the weight constraint (2) it implies that overweight of person i is obtained as (6).

$$o_t(i) = \max\left\{0, \ \frac{\alpha}{s_t + \eta} - \omega(i)\right\}, \qquad \omega(i) \equiv (1 - \alpha)\left(\frac{\epsilon y(i)}{\beta(i) - p_t} - \mu(i)\right). \tag{6}$$

2.3. **Comparative Statics.** We next discuss the solution for given prices p_t and social approval s_t. As shown in (6) excess food consumption of individual i is decreasing in the degree of social disapproval of overweight s_t. For any given s_t, inspection of (6) proves the following results on comparative statics.

Proposition 1. *Consider a society defined as a distribution of tastes $\beta(j)$ and incomes $y(j)$ for citizens $j \in N$. Then, the probability that a person i is overweight is decreasing in* *her or his personal income $y(i)$, the unhealthiness of being overweight η, the price of food p_t, and the energy exchange rate ϵ. It is increasing in the personal degree of gratification from food consumption $\beta(i)$ and the weight of consumption in utility α.*

PROPOSITION 2. *The weight of an overweight person i is decreasing in income $y(i)$, the unhealthiness of being overweight η, the price of food p_t, and the energy exchange rate ϵ. It is increasing in the personal degree of gratification from food consumption $\beta(i)$ and the weight of consumption in utility α.*

The result with respect to income helps to explain the observed negative socioeconomic gradient in obesity, that is why – ceteris paribus – richer people are less heavy. For an intuition it is useful to return to the first order condition (4). Higher income allows for a higher level of consumption, $c + \beta v$, be it in terms of food or non-food. A higher level of consumption in turn means lower marginal utility from consumption relative to the marginal disutility experienced from being overweight. It implies that the marginal utility experienced from being less heavy, measured by the right hand side (4), is higher for richer persons. In simple words, when many consumption needs are fulfilled, health considerations and social approval of one's appearance becomes relatively more important for individual happiness. Consequently, richer persons are, on average, less heavy.

The other comparative static results from Proposition 1, except for the energy exchange rate, are immediately intuitive. The result with respect to the energy exchange rate, at first sight, appears to contradict the empirical observation that obese people are consuming particularly energy-dense food. Within the present framework, however, the seemingly counterfactual result is consistently explained: a higher energy exchange rate increases the negative consequences of excess food consumption on health and social disapproval, a fact, which discourages the incentive to eat a lot. In order to explain the empirical regularity between energy density and obesity the model has to be extended by allowing individuals to chose a particular diet. This will be done in Section 4. The seemingly counterfactual result will be resolved by allowing energy-dense diets to be either cheaper or more pleasurable or both. All other results from the simple model will be preserved.

2.4. **Social Disapproval.** Inspired by the observed social attitudes towards obesity (presented in the Introduction) we assume that social disapproval of obesity is inversely related to the actual prevalence of obesity in society. The simplest conceivable way to implement this notion is to assume that social disapproval is inversely related to overweight of the median citizen, denoted by by $\bar{o}_t$. Henceforth idiosyncratic parameters that apply to the median are identified by "upper bars", that is, for example, $o_t(i) = \bar{o}_t$ for the median.

In order to discuss social dynamics explicitly we assume that social disapproval evolves as a lagged endogenous variable depending on the observation of actual obesity in the history of the society. Let δ denote the time discount rate or rate of oblivion by which the historical prevalence of obesity is depreciated in mind so that disapproval is given by $s_t = (1-\delta)\sum_{i=0}^{\infty} \delta^i \bar{g}(\bar{o}_{t-1-i})$. Alternatively, this can be written in period-by-period notation as $s_t = \delta \cdot s_{t-1} + (1-\delta) \cdot g(\bar{o}_{t-1})$. Using the simplest conceivable inverse function $g(o) = 1/(\gamma + o)$, social disapproval of overweight in period t can be expressed as

$$s_t = \delta \cdot s_{t-1} + (1-\delta) \cdot g(\bar{o}_{t-1}), \qquad g(\bar{o}) \equiv \frac{1}{\gamma + \bar{o}}. \tag{7}$$

The parameter δ controls the speed of social evolution and the parameter γ controls the strength of social norms; $1/\gamma$ is the maximum disapproval generated by society, that is the disapproval (per kilogram overweight) that a person experiences when the median citizen is lean.

3. The Social Evolution of Obesity

3.1. **Steady-State.** At the steady-state, $p_t = p$, $s_t = s$, and $\bar{o}_t = \bar{o}$ for all t and solving (7) for s provides (8).

$$s = g(\bar{o}) \equiv \frac{1}{\gamma + \bar{o}}. \tag{8}$$

From (6) we observe excess food consumption of the median citizen in period t as $\bar{o}_t = \alpha/(s_t + \eta) - \bar{\omega}$, in which the compound parameter $\bar{\omega}$ summarizes the impact of preferences and income of the median, $\bar{\omega} = (1-\alpha)[\epsilon\bar{y}/(\bar{\beta} - p_t) - \mu]$. Solving for s_t

$$s_t = \frac{\alpha}{\bar{o}_t + \bar{\omega}} - \eta \equiv h(\bar{o}_t). \tag{9}$$

Diagrammatically, (8) and (9) establish two equations for social disapproval. Equation (9) holds everywhere, equation (8) holds only at the steady-state, implying that the steady-state fulfils both equations. Equating (8) and (9) and solving for $\bar{o}$ provides (10).

$$\bar{o} = o^* = -\frac{r}{2} + \sqrt{\frac{r^2}{4} - q}, \qquad r \equiv \frac{1 - \alpha + \eta(\bar{\omega} + \gamma)}{\eta} > 0 \qquad q \equiv \frac{\bar{\omega}(1 - \eta\gamma) - \alpha\gamma}{\eta}. \tag{10}$$

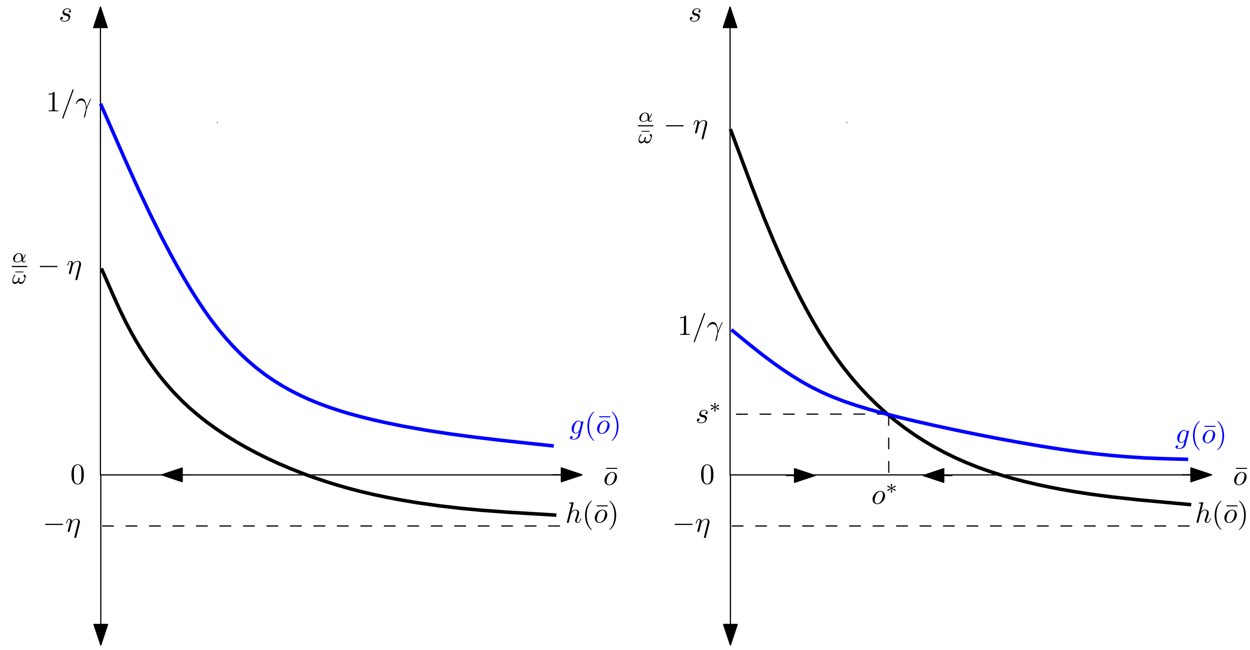
From the fact that $r > 0$ follows that there exists a unique steady-state at which the median is overweight iff $q < 0$, that is iff $1/\gamma < (\alpha/\bar{\omega}) - \eta$.

The steady-state and its comparative statics can be best analyzed diagrammatically. For that purpose note that both $g(\bar{o})$ and $h(\bar{o})$ are decreasing and concave in $\bar{o}$. The graph of $g(\bar{o})$ originates at $1/\gamma$ and approaches zero as $\bar{o}$ goes to infinity. The graph of $h(\bar{o})$ originates at $\alpha/\bar{\omega}) - \eta$ and approaches $-\eta$ as $\bar{o}$ goes to infinity. From (10) we know that there exists either no or one intersection in the positive quadrant, identifying the obesity equilibrium. These two cases are displayed in Figure 1.

If there exists no intersection of $g(\bar{o})$ and $h(\bar{o})$, as displayed on the left hand side of Figure 1, there exists no steady-state of obesity as a social phenomenon. For any given perturbation resulting in overweight of the median, social disapproval s is higher than the level needed to sustain this weight as a steady-state. Consequently, the median eats less until he or she returns to the corner solution where $\bar{o} = 0$. At the steady-state the median citizen is not overweight. This in turn means that, although there are overweight persons in society at the steady-state (for example those poorer than the median or those with a "sweeter tooth"), being overweight is not supported by a social norm and there exists no obesity epidemic. Any perturbation or any *marginal* change of parameters would induce adjustment dynamics back to $\bar{o} = 0$. There is no permanent evolution towards larger bodies in society.

The right hand side of Figure 1 shows the other, more interesting, possibility. Here the $h(\bar{o})$–curve lies above the $g(\bar{o})$ curve for small $\bar{o}$. This means that for any overweight $\bar{o} < o^*$

Figure 1: Steady-States and Dynamics: Lean vs. Overweight Median



Left hand side: no equilibrium with excess food consumption of the median citizen: For any given overweight $\bar{o}$ of the median citizen, social disapproval is higher than needed to sustain $\bar{o} > 0$ as a steady-state. Right hand side: Stable equilibrium at which overweight of the median o^* is supported as a steady-state.

social disapproval is lower than needed to sustain this weight as a steady-state. Consequently, the median citizen (and thus any overweight person in society) eats more and puts on more weight and social disapproval of being overweight decreases until $\bar{o}$ is supported by the social norm at o^*. Excess weight above o^*, on the other hand, is not sustainable. The associated disapproval leads to less excess food consumption and less overweight. In other words, the equilibrium at o^* is stable. The following proposition summarizes the results.

Proposition 3. *There exists a stable steady-state at which the median citizen is overweight and being overweight is supported by the social norm iff*

$$\frac{1}{\gamma} < \frac{\alpha}{\bar{\omega}} - \eta. \tag{11}$$

Otherwise, the median citizen is not overweight at the steady-state.

Proposition 4. *There exists a stable steady-state at which the median citizen is overweight and being overweight is supported by the social norm if individuals care sufficiently little about the consequences of being overweight (if α is sufficiently large), if being overweight entails sufficiently minor consequences on health (if η is sufficiently low), if the steady-state price of food is sufficiently low (p is sufficiently low), if the median citizen likes eating sufficiently strongly (if $\bar{\beta}$ is sufficiently large), and if the median is sufficiently poor ($\bar{y}$ is sufficiently low).*

The proof evaluates $\omega(i)$ in (6) for the median and inserts the result into (11) which provides the condition

$$\frac{1}{\gamma} + \eta < \frac{\alpha}{1-\alpha} \cdot \frac{\bar{\beta} - p}{\epsilon \bar{y} - (\bar{\beta} - p)\bar{\mu}}. \tag{12}$$

Inspection of (12) verifies the proposition.

Using Proposition 1 and 2 and inspecting Figure 1 it is straightforward to derive the comparative statics of the social equilibrium. For that purpose it is helpful to note that the $g(\bar{v})$-curve remains unaffected by value changes of the parameters α, $\bar{\beta}$, p, $\bar{y}$, $\bar{\mu}$, and η. The fact that Proposition 2 holds true for any person (and thus in particular for the median citizen) and at any s_t (and thus in particular at the steady-state) implies that comparative statics for these parameters can be obtained simply be observing how they shift the $\bar{h}(\bar{o})$-curve. Applying Proposition 2 we see that increasing α, $\bar{\beta}$ and decreasing η, p, and $\bar{y}$ shift the $h(\bar{o})$-curve to the right, in direction of heavier bodies. This observation proves the following proposition.

Proposition 5. *If a social equilibrium of obesity o^* exists, then the median citizen is heavier and the prevalence of overweight in society is higher if individuals care less about the consequences of eating (if α is larger), if the median has a greater preference for eating (if $\bar{\beta}$ is larger), if health consequences of overeating are smaller (if η is smaller), if the price of food p_t is lower, and if the median citizen is poorer (if $\bar{y}$ is smaller).*

The last result provides a rationale for why, apparently, obesity is more prevalent in unequal societies (see the Introduction). Ceteris paribus, the median is poorer in unequal societies and – due to the mechanism explained above – motivated to eat more. This implies that being overweight attracts less social disapproval and that other members of society are (more severely) overweight as well.

The comparative static remaining to be discussed is on γ. For that purpose note that the size of γ affects only the $g(\bar{o})$–curve but not the $h(\bar{o})$–curve. A higher γ shifts the $g(\bar{o})$ curve downwards. This means that, if a social equilibrium of obesity o^* exists, the median is heavier and the prevalence of overweight in society is higher if overweight is less punished with disapproval by society.

Shifts of parameters that apply to all citizens have a two-fold consequence on individual body size. There is a social multiplier at work. We next consider two examples for the multiplier with interesting and perhaps non-obvious results.

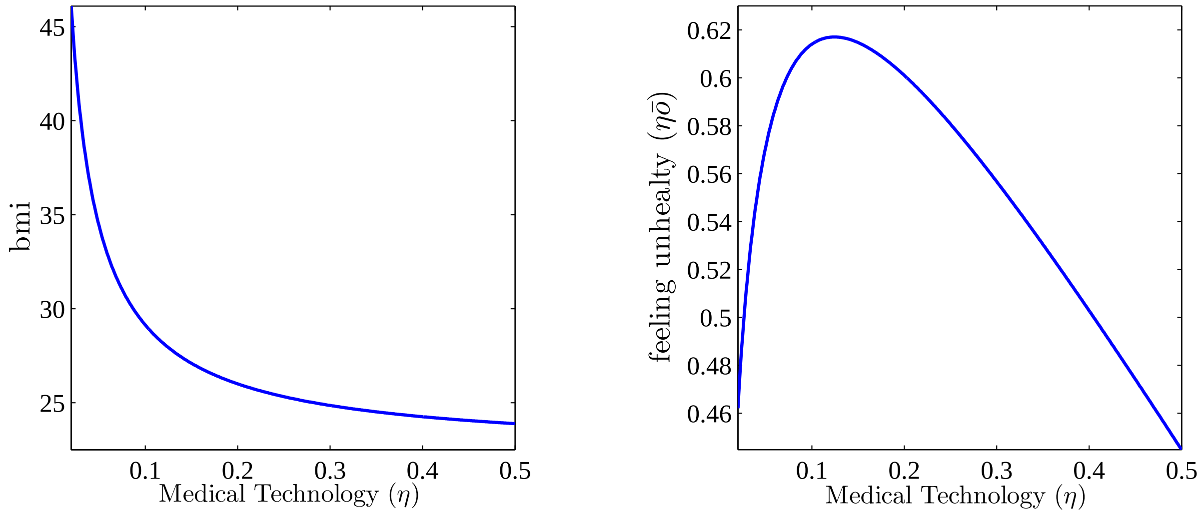
3.2. **Feeling Unhealthy.** If medical technological progress (e.g. the arrival of beta blockers, dialysis, coronary stents) reduces the health consequences of being overweight, some persons are motivated to eat more. If the median is among these persons, which is the case when o^* exists, there is a social multiplier at work. Formally we can define unhealthiness as the part $\eta \cdot o_t \equiv u(o_t)$ in utility. Evaluating this expression for the median at the steady-state and taking the first derivative with respect to η we get:

$$\frac{\partial u}{\partial \eta} = \bar{o} + \eta \cdot \frac{\partial \bar{o}}{\partial \eta}. \tag{13}$$

The first term in (13) identifies the direct effect of the health innovation on health of the median. It is positive. For *decreasing* η, representing medical technological progress, this means that the median feels less unhealthy. This fact, however, motivates her (and thus a majority of society) to eat more and to put on more weight. The second term in (13) identifies the negative consequences of increasing body weight on health through the social multiplier. It is negative (recall Proposition 2).

Due to the counteracting forces on the response of unhealthiness, it can happen that the social effect dominates the individual effect such that the median (and other members of society) are less healthy at the new steady-state after a positive innovation of health technology. Figure 2 verifies this claim by way of example. It shows the steady-state value of weight (bmi)

Figure 2: Medical Technology, Obesity, and Health of the Median Citizen



Evaluated at steady-state. Lower values of η are associated with a higher level of medical technology. Body mass index (bmi) is given by $\bar{\mu}+\bar{o}$. Unhealthiness is measured by $u(\bar{o}) = \eta\bar{o}$. Parameters: $p = 1$, $\alpha = 0.8$, $\bar{\beta} = 2$, $\gamma = 50$, $\epsilon = 2.5$, $\bar{\mu} = 23$, $\bar{y} = 10$.

and the experienced unhealthiness by the median for alternative levels of medical technology. Without excess eating the parameterized median would have a lean body mass index $\bar{\mu}$ of 23. Values for the other parameters are given below Figure 2. Coming from a low level of obesity-related health technology, that is from high η, a situation, which is associated with a mildly overweight median citizen, the social multiplier causes the median to be heavier and unhealthier at the steady-state when η decreases. This means that unhealthiness $u(\bar{o})$ is a increasing with medical technological progress. Only if the state of medical technology is very high, the $u(\bar{o})$ curve is positively sloped, implying that further improving technology leads to less severe health consequences at the steady-state.

3.3. **Feeling Fat.** A similar consideration can be made for the impact of social attitudes on self-perception. The impact of social disapproval on the experienced disutility from being overweight is measured by the degree of "feeling fat" $f(o_t) \equiv s_t o_t$. Evaluating the expression for the median at the steady-state,

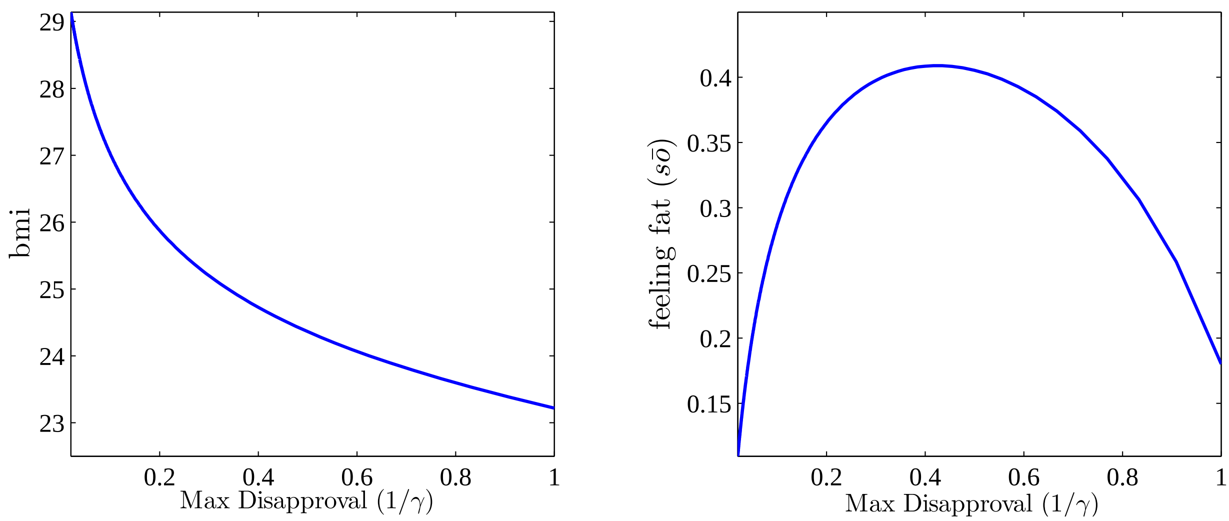
$$f(\bar{o}) = \frac{\bar{o}}{\gamma + \bar{o}},$$

and taking the derivative with respect to γ we obtain (14).

$$\frac{\partial f(\bar{o})}{\partial \gamma} = -\frac{1}{(\gamma+\bar{o})^2} \cdot \bar{o} + \frac{\gamma}{(\gamma+\bar{o})^2} \cdot \frac{\partial \bar{o}}{\partial \gamma}. \tag{14}$$

The first, negative term identifies again the direct effect. When γ rises, individuals experience less social disapproval at any given body size. The median (and other persons in society) are feeling less fat. At a steady-state of obesity o^*, however, this fact motivates to eat more and to put on more weight. The negative effect of the social multiplier on disapproval is measured by the second, positive term. Individuals "feel fatter" due to the weight gain.

Figure 3: Social Disapproval of Overweight, Obesity, and "Feeling Fat" of the Median Citizen



Evaluated at steady-state. Lower values of $1/\gamma$ are associated with lower social disapproval of being overweight. Body mass index (bmi) is given by $\bar{\mu} + \bar{o}$. The degree of "feeling fat" is given by $f(\bar{o}) = \bar{o}/(\gamma + \bar{o})$. Parameters as for Figure 2 and $\eta = 0.1$.

Again, it can happen that the social effect dominates the direct effect. Another example, shown in Figure 3, corroborates this claim. It shows the steady-state weight (bmi) and the experienced utility loss from social disapproval for alternative values of γ. When disapproval for being overweight is very low ($1/\gamma$ is low), the median citizen is very fat at the steady-state but suffers relatively little from the evaluation of others. Many other citizens are anyway obese themselves. At the other extreme, when being overweight is severely punished with disapproval, the median is only mildly overweight and suffers mildly from "feeling fat". At an intermediate degree of social disapproval and an intermediate degree of overweight the suffering from social disapproval is largest. In other words, coming from the right from a situation of high social disapproval of overweight (high $1/\gamma$), less disapproval per unit of overweight leads to heavier persons and actually to more suffering from social disapproval.

3.4. **Bmi Distribution.** At a steady-state of obesity o^* any overweight person responses in the same direction as the median to changes of common parameters (recall Proposition 2). Quantitatively, however, individuals can response quite differently. To see that, take the difference of overweight for any to persons, $i = j, k$ at the steady-state. From from (5) we get

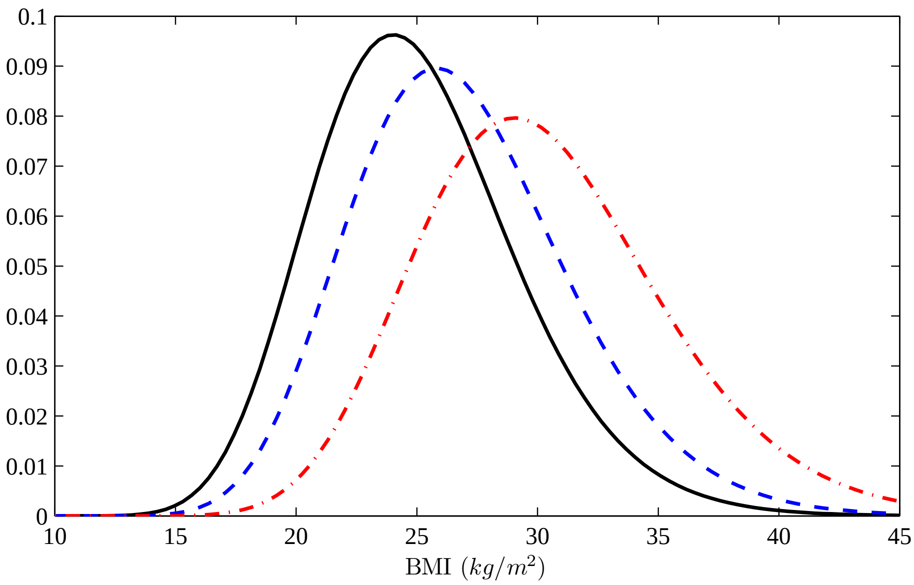
$$o(j) - o(k) = (1 - \alpha) \left[\mu(j) - \mu(k) - \left(\frac{\epsilon y(j)}{\beta(i) - p} - \frac{\epsilon y(k)}{\beta(k) - p} \right) \right]. \tag{15}$$

The result shows that a change of almost any parameter changes the relative position of individuals in the weight distribution. A comprehensive discussion of the effect of innovations on overweight of all citizens would thus require to specify a distribution of preferences and incomes.

But inspection of (15) also shows that value changes of η and γ do not affect the differential $o(j) - o(k)$. Since this is true for any j and k, it means that changes of these parameters do not change the standard deviation for any given distribution of body mass. The effect of a change of η or γ on body size can thus be discussed conveniently not only with respect to the median citizen but with respect to the society at large.

Empirical studies have shown that the bmi distribution in developed countries is approximately log-normally distributed. Inspired by this fact we assume that – caused by differences in preferences and income – log bmi is normally distributed with variance σ. The black curve in Figure 4 shows the density function of a log-normal distribution such that is approximates the actually observed density function in 1971-75 (see Cutler et al., 2003, and Veerman et al., 2007). In particular, we have assumed that $\eta = 0.1$ and adjusted σ to 0.17 in order to fit the empirical observation. The blue (dashed) line shows the resulting weight distribution after a medical technological innovation had lowered the consequences of obesity. Specifically, η had been reduced by one half to 0.05. The bmi distribution shifts to right and the right hand tail

Figure 4: Obesity Distribution for Alternative Levels of Medical Technology



Parameters: $p = 1$, $\alpha = 0.8$, $\bar{\beta} = 2$, $\epsilon = 4$, $\bar{\mu} = 22$, $\bar{y} = 10.5$, $\sigma = 0.17$, and $\eta = 0.1$ (low medical technology, solid black), $\eta = 0.075$ (medium medical technology, dashed blue), $\eta = 0.05$ advanced medical technology, dash-dotted red).

gets fatter. The result roughly approximates the actual movement documented by Cutler et al. and Veerman et al. The red (dash-dotted) line represents the prediction of the obesity distribution after further reduction of η by one half to 0.025.

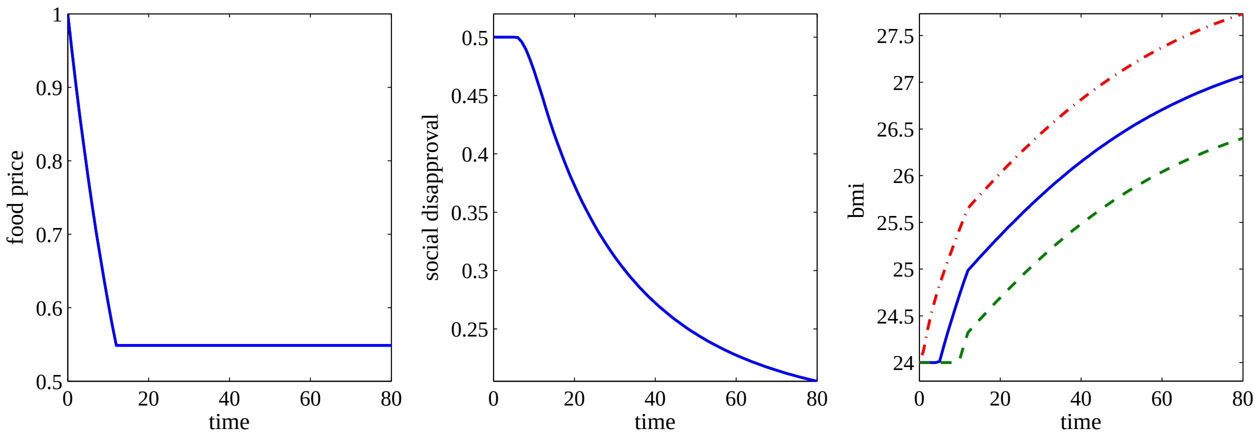
3.5. **Adjustment Dynamics: The Evolution of Overweight and Obesity.** Innovations in medical technology can explain the actual evolution of the bmi distribution only imperfectly. The last decades have seen other, potentially more important body-size affecting changes. In particular, a falling relative price of food has been proposed in the literature. Some researchers, however, are confused by the observation that the major decrease of food prices occurred in the 1970 and 1980 while body weight continued to grow until today (Cutler et al., 2003, Ruhm, 2010). The present model is helpful in resolving the puzzle. With a social multiplier at work it can well be that most of the increase of body size occurs long after the drop of food prices. In other words, lower food prices have *initiated* the rise of body weight, but it is the social multiplier that developed it further and amplified it such that the phenomenon evolved towards an "obesity epidemic" which affects a majority of society.

We next demonstrate the social evolution of obesity and the power of the social multiplier with a numerical example. For that purpose we set weight (bmi) of the non-overweight median $\bar{\mu}$ to 24 kg. We think of the period length as of one quarter and set the time discount rate δ to 0.9. A high time discount rate generates high persistence of bmi i.e. a slow evolution of body mass. A value of 0.9 may be regarded as high but compared to what is calibrated elsewhere in dynamic economics (e.g. values round 0.98 in business cycle theory, see e.g. King and Rebelo, 1999) it is actually comparatively low. Furthermore we assume a relatively low value of γ, $\gamma = 2$, in order to generate substantial variability in the social disapproval of obesity. The full set of parameter values is specified below Figure 5.

For the initial price of food, $p(0) = 1$, the system is situated in the lean steady-state. Small perturbations and small changes of parameters do not affect existence of the steady-state. Driven by social disapproval the median always returns to lean body mass and the bmi distribution in society is time-invariant. This setup approximates the historical situation in the US and many other developed countries before the 1980s (see Introduction). The experiment shown in Figure 5 assumes that, starting in such a situation, the price of food drops by 5 percent per quarter for 12 quarters. The solid line in the right panel shows the initiated evolution of median bmi. During the first half of the period of declining food prices, body weight of the median stays constant; the system is still associated with the lean steady-state. Only after food prices have been falling long enough, the lean steady-state becomes non-existent and the median citizen puts on weight and social disapproval of being overweight deteriorates.

After 12 quarters the price stops declining but the social multiplier continues to operate. The new steady-state is not yet reached. Actually, we observe that median weight in society increases by more during the period of constant prices than during the period of declining prices. Because social disapproval of being overweight continues to decline, the median (and thus society at large) continues to eat more, which in turn further reduces social disapproval etc. An observer unaware of the underlying social dynamics might thus wrongly conclude that falling food prices cannot have caused the obesity epidemics. A similar argument can be made with respect to the preference parameter $\bar{\beta}$, which affects overweight inversely to p (see equation (6)). Technological innovations which improved the palatability (flavor enhancer) or availability (convenience food) of food and therewith increased its likeability, measured by an increase of $\bar{\beta}$, can have initiated an obesity evolution, which becomes only fully visible long after the innovation took place.

Figure 5: Social Evolution of Obesity



The figure displays dynamics after a drop of food prices by 5 percent per quarter in quarter 0-12. Parameters: $p = 1$, $\alpha = 0.9$, $\bar{\beta} = 1.75$, $\gamma = 2$, $\epsilon = 4$, $\bar{\mu} = 24$, $\delta = 0.9$, and $\eta = 0.02$. Income: $\bar{y} = 10$ (median, blue); $y_p = 8$ (red); $y_r = 12$ (green).

The dashed (green) and dash-dotted (red) lines in Figure 5 reflect the associated bmi evolution for individuals which are 20 percent richer or poorer, respectively, than the median but face otherwise identical preferences and technologies. While the poor individual reacts immediately on falling food prices, the rich individual keeps a lean body as long as prices are falling (caused by the yet high social disapproval for a non-lean appearance) and starts putting on weight only after food prices have settled down. One could thus argue that overeating of the rich individual was not motivated by falling prices but by declining social disapproval. This view, however, fails to acknowledge that falling food prices and the triggered median behavior have caused social disapproval to decline sufficiently such that overeating became attractive for the rich individual.

4. Extensions

4.1. **Physical Exercise and Weight Loss.** In this section we investigate robustness of results when individuals have the possibility to loose weight through physical exercise. In order to simplify the analysis we assume that exercising is done during leisure time and that all individuals are equipped with one unit of leisure time. An individual i who decides to spend $e_t(i)$ units of leisure on physical exercises, gets rid of $\lambda e_t(i)$ units of body weight, that is $o_t(i) = \epsilon v_t(i) - \mu(i) - \lambda e_t(i)$. The parameter λ controls how effective exercising is with respect to weight loss.

The opportunity cost of exercising is that less leisure time is available for other activities. In order to make the problem interesting we assume that the median citizen likes other activities better than weight-loss activities. Otherwise, he or she would go for the corner solution, $e_t(i) = 1$. In that case, if he or she continues to be overweight, the solution is isomorph to the one of the simple model. The interesting case is thus the interior solution, in which not all leisure time is spend on weight loss activities. Specifically we assume that exercising $e_t(i)$ units of time reduces utility by factor $(1 - e_t(i))^{\phi(i)}$. The parameter $\phi(i)$ controls how much the person dislikes physical exercise compared to other leisure activities, $0 < \phi(i) < 1$. The assumption that $\phi(i)$ is bounded from above by unity prevents that the only solution is at the other corner, at which no time is spent on weight loss activities, a choice, which would again imply results isomorph to the ones of the basic model. With these amendments utility of person i can be rewritten as (16).

$$u_t(i) = [c_t(i) + \beta(i)v_t(i)]^{\alpha} \cdot [1 - (s_t + \eta)(\epsilon v_t(i) - \mu(i) - \lambda e_t(i))]^{1-\alpha} \cdot [1 - e_t(i)]^{\phi(i)} . \qquad (16)$$

The first order condition with respect to food consumption and exercise can be solved for the interior solution (17) and (18). They imply overweight (19).

$$v_t(i) = \frac{\alpha(\beta(i) - p_t) + (s_t + \eta)\left[\epsilon y(i) + (\beta(i) - p)\mu(i)\right] + \alpha\lambda(s_t + \eta)(\beta(i) - p_t)}{(\beta(i) - p_t)(s + \eta)(1 - \phi(i))} \qquad (17)$$

$$e_t(i) = \frac{\phi(i)\left\{(\beta(i) - p_t) + (s_t + \eta)\left[\epsilon y(i) + (\beta(i) - p_t)\mu(i)\right]\right\}\lambda(s_t + \eta)(\beta(i) - p_t)\lambda}{(\beta(i) - p_t)(s + \eta)(1 - \phi(i))} \qquad (18)$$

$$o_t(i) = \frac{(\alpha - \phi(i))(\beta(i) - p_t) + (s_t + \eta)(1 - \alpha)\left[(\beta(i) - p)\mu(i)\epsilon y(i)\right] - (1 - \alpha)\lambda(s_t + \eta)(\beta(i) - p_t)}{(\beta(i) - p_t)(s + \eta)(1 - \phi(i))} \tag{19}$$

The solutions for $v_t(i)$ and $o_t(i)$ look structurally similar to those for the simple model. But there are also interesting differences. Taking the derivatives with respect to income provides:

$$\frac{\partial e_t(i)}{\partial y_t(i)} = \frac{\epsilon\phi(i)}{D} > 0, \qquad \frac{\partial v_t(i)}{\partial y_t(i)} = -\frac{1 - \alpha - \phi(i)}{D}, \qquad \frac{\partial o_t(i)}{\partial y_t(i)} = -\frac{(1 - \alpha)\epsilon}{D} < 0,$$
$$D \equiv (\beta(i) - p_t)(1 - \phi).$$

Recalling that $\beta(i) > p$ is necessary for overweight and observing the sign of the derivatives proves the following proposition.

Proposition 6. *Ceteris paribus, individuals with higher income exercise more for weight loss and are less overweight. They eat less if $\phi(i) < 1 - \alpha$.*

The possibility of getting rid of weight through exercising breaks the causal link from food consumption to overweight. Only if the impact of body size for utility is sufficiently large ($1 - \alpha$ is sufficiently large), richer people eat less. Otherwise they eat more and work out the weight gain through increased exercising. In any case, however, the original result that richer individuals are, ceteris paribus, less overweight is preserved. In line with the empirical observation the extended model predicts that richer people, on average, exercise more for weight loss (Gidlow et al., 2006).

For social dynamics the impact of s_t on body weight is of particular interest. Taking the derivatives we obtain:

$$\frac{\partial e_t(i)}{\partial s_t} = -\frac{\phi(i)}{\lambda\tilde{D}} < 0, \qquad \frac{\partial v_t(i)}{\partial s_t} = -\frac{\alpha}{\tilde{D}} < 0. \qquad \frac{\partial o_t(i)}{\partial s_t} = -\frac{(\alpha - \phi(i))}{\tilde{D}}.$$
$$\tilde{D} \equiv (s_t + \eta)^2(1 - \phi(i)).$$

As for the simple model, individuals react to increasing social disapproval of being overweight with eating less. Maybe surprisingly, they also exercise less. This is explained as follows. A higher disapproval s_t increases the marginal utility from exercising with respect to weight loss. At an interior optimum this implies that the marginal disutility from exercising due to lost leisure time must also increase. For that, e_t has to decrease. The reaction of exercise implies that the response of overweight is generally ambiguous. In order to preserve the mechanism and results from the simple model, we have to assume that the median citizen likes consuming sufficiently strongly, $\alpha > \bar{\phi}$, that is that he regards consuming more important than not exercising. This restriction appears to be rather mild.

4.2. **Diet Selection, Energy-Density, and Obesity.** In this section we explore one possible explanation of the positive association between energy-density and obesity. For that purpose we extend the model such that there are two food goods. The unhealthy good, identified by index u is relatively cheap, energy dense, and potentially tasty (junk food). The second good is relatively expensive, light, and potentially less palatable. Since the expressions become rather long we omit the time index and the index i for idiosyncratic variables whenever this does not lead to confusion. Specifically we assume that

$$(\beta_u - p_u) > (\beta_h - p_h), \qquad \epsilon_u > \epsilon_h.$$

Good u is cheaper or more preferable or both compared to good h and its energy exchange rate is higher. Let v_u and v_h denote consumption of good u and good h. The budget constraint and weight constraint are then given by

$$y = c + p_u v_u + p_h v_h \tag{20}$$

$$o = \epsilon_u v_u + \epsilon_h v_h - \mu. \tag{21}$$

Furthermore, we allow consumption of good u to be unhealthy beyond its impact on weight (for example because of high content of sugar or trans-fats) and measure the health effect by the parameter σ. Using this fact and (20) and (21) utility (3) can be restated as

$$U = [y + (\beta_u - p_u)v_u + (\beta_h - p_h)v_h]^{\alpha} \cdot [1 - (s + \eta)(\epsilon_u v_u + \epsilon_h v_h - \mu) - \sigma v_u]^{1-\alpha}. \tag{22}$$

Individuals are maximizing utility by choosing $v_u \geq 0$ and $v_h \geq 0$. The double linearity in (20) and (21) implies that only corner solutions are optimal. Individuals either chose the healthy diet or the unhealthy diet.[3] In the Appendix it is shown that the solution is either v_u or v_h:

$$v_u = \frac{\alpha(\beta_u - p_u) + (s+\eta)\left[\alpha(\beta_u - p_u)\mu - (1-\alpha)\epsilon_u y\right] - \sigma(1-\alpha)y}{(\beta_u - p_u)\left[\epsilon_u(s+\eta)+\sigma\right]}, \tag{23}$$

$$v_h = \frac{\alpha(\beta_h - p_u) + (s+\eta)\left[\alpha(\beta_h - p_h)\mu - (1-\alpha)\epsilon_h y\right]}{(\beta_h - p_h)\epsilon_h(s+\eta)}. \tag{24}$$

Inspecting (24) and (5) let us conclude that the solution for the healthy diet v_h is isomorph to the solution of the simple one-diet model. The interesting case is thus when at least some individuals prefer the unhealthy diet. Their overweight is then given by $o_u = \epsilon_u v_u - \mu$, that is by

$$o_u = \frac{\alpha\epsilon_u(\beta_u - p) - (1-\alpha)\left[\epsilon_u(s+\eta)+\sigma\right]\epsilon_u y + \alpha\epsilon_u(s+\eta)(b_u - p_u)\mu}{(\beta_u - p_u)\left[\epsilon_u(s+\eta)+\sigma\right]} - \mu. \tag{25}$$

Inspecting the response of overweight on energy-density provides the following result.

Proposition 7. *Consider a person who prefers the unhealthy diet and is overweight. Then, an increase in the energy exchange rate ϵ_u results in even more overweight for any given level of social approval s if the unhealthy food is sufficiently cheap (p_u sufficiently low) or sufficiently tasty (β_u sufficiently large) or if the person is sufficiently poor (y is sufficiently low).*

The proof evaluates the first order derivative

$$\frac{\partial o_u}{\partial \epsilon_u} = \frac{\alpha(\beta_u - p_u)\sigma\left[1+(s+\eta)\mu\right] - (1-\alpha)\left[\sigma+\epsilon_u(s+\eta)\right]^2 y}{(\beta_u - p_u)\left[\sigma+\epsilon_u(s+\eta)\right]^2}$$

and the second order derivatives

$$\frac{\partial^2 o}{\partial \epsilon_u \partial y} = -\frac{1-\alpha}{\beta_u - p_u} < 0, \qquad \frac{\partial^2 o}{\partial \epsilon_u \partial(\beta_u - p_u)} = \frac{1-\alpha}{(\beta_u - p_u)^2} > 0.$$

[3]To square results with reality the reasonable interpretation of a corner solution is thus that diet h is more healthy *on average* and may in practice include an *occasional* donut.

Observing that one can always find a $(\beta_u - p_u)$ high enough and an y low enough such that $\partial o_u / \partial \epsilon_u > 0$ completes the proof.

For social dynamics and steady-states it now matters whether the median prefers the healthy or the unhealthy diet. Naturally, in case of a healthy diet all results from the simple model carry over to the two-diet model, because the solution for the median is isomorph. If the median prefers the unhealthy diet, results are generally ambiguous. The response of overweight on social disapproval is obtained as

$$\frac{\partial o_u}{\partial s} = -\frac{\alpha \epsilon_u (\epsilon_u - \sigma \mu)}{[\epsilon_u (s + \eta) + \sigma]^2}$$

Increasing social disapproval of being overweight evokes the normal response of weight loss if the constraint $\epsilon_u > \sigma \mu$ holds. This means the energy density of the unhealthy good must be sufficiently high. In this case, as well as generally if the median citizen picks the healthy diet, all results from the basis model carry over to the two-diet-model.

Comparing the dietary choices (23) and (24) shows that one can always find a triple $\{\beta_u, \beta_h, y\}$ for which the unhealthy diet is strictly preferred. Since consumption under both diets is strictly decreasing in income, body weight in a society which is stratified only by income is distributed as follows. The poorest individuals indulge the cheap unhealthy diet and are potentially overweight. At some level of income, $v_u \geq 0$ becomes binding with equality and the richer individuals enjoy the healthy diet. While they are potentially overweight as well, eventually, as income rises further, the metabolic constraint $\epsilon_h v_h - \mu \geq 0$ becomes binding with equality. The richest individuals – due to the mechanism explained in Section 2 – refrain from excess food consumption and are not overweight.

Living on the unhealthy diet, however, makes not *necessarily* fatter. To see this, consider a society stratified only by food preferences, β_u and β_h, and focus on the limiting case, in which diet u is not unhealthy aside from its energy density, that is $\sigma = 0$. Holding income y (and lean body size μ) constant, computing $o_h(v_h) = \epsilon_h v_h - \mu$ from (24) and subtracting it from

(23) provides the body size differential

$$o(v_u) - o(v_h) = \frac{(\beta_u - p_u)\epsilon_h - (\beta_h - p_h)\epsilon_u}{(\beta_u - p_u)(\beta_h - p_h)} \cdot (1 - \alpha)y.$$

The unhealthy eaters are thus only bigger if

$$\frac{\beta_u - p_u}{\beta_h - p_h} > \frac{\epsilon_u}{\epsilon_h}.$$

That is, only if eating the unhealthy food provides sufficiently great pleasure or if it is sufficiently cheap compared to its energy exchange rate and relatively to the healthy good, are the unhealthy eaters more overweight.

4.3. **Food Price Policy.** If a social equilibrium of obesity exists, the government might want to manipulate food prices. This activism could be motivated by the fact that external effects are responsible for overeating and that obesity as a mass phenomenon would potentially not arise without the social multiplier. Moreover, as it has been shown in case of medical innovations, the social multiplier may have the power to turn an originally health-improving innovation unhealthy. In a stratified society, however, with heterogeneous dietary choices, a price policy on unhealthy food may be ineffective. To see this, first reconsider the one-diet model and the following result.

PROPOSITION 8. *Without dietary choice, a sufficiently strong increase of food prices can free a society from the obesity equilibrium and initiate a development towards a lean median citizen and less prevalence of overweight in society.*

For the proof recall from (6) that rising p increases $\bar{\omega}$ and from Proposition 3 and Figure 1 that a higher $\bar{\omega}$ shifts down the $h(\bar{o})$ curve. A sufficiently strong downward shift eliminates the obesity equilibrium (intersection of curves). Responses of the other citizens follow from Proposition 1 and 2.

For the two-diet model the same mechanism applies if the median indulges the unhealthy diet. However, if the median lives on a healthy diet but is nevertheless overweight, increasing the price of the unhealthy good (by a fat tax) is non-effective. This can be seen immediately by recalling that if the median lives on the healthy diet, the solution of the two-diet model is isomorph to the one from the simple model . A price change for the *unhealthy* diet thus does not effect the equilibrium o^*. The following proposition summarizes this insight.

Proposition 9. *With dietary choice, increasing the price of the unhealthy good cannot eliminate the social equilibrium of obesity if the median is overweight on a healthy diet.*

The result points to the potential limitations of a fat tax. If it does not apply to the median's diet the price change does not induce a society-wide behavioral change. It affects some poor persons who in response eat less of the unhealthy diet. Some of them may even be nudged to switch to the healthy diet. As a result they become less overweight and less happy. The external effect and the social multiplier, however, are still active and keep society, on average, overweight.

5. Final Remarks

This paper has proposed a theory of the social evolution of overweight and obesity which explains the changing human phenotype since the 1980s. A social multiplier rationalizes why declining food prices or technological innovations could have initiated an obesity epidemic although the most dramatic weight gain is observed long after the initiating innovation is gone. The social multiplier can also explain how obesity-related health innovations may have detrimental steady-state effects on health and why unequal societies are, ceteris paribus, heavier. Within societies the theory explains the socio-economic gradient, i.e. why poorer people are more severely afflicted by obesity although eating a lot is costly. Extensions have shown that the basic mechanism is robust against the consideration of dietary choice and exercising for weight loss. The extensions have furthermore provided theoretical support for the observation that exercising is more popular among richer individuals as well as a condition under which an increasing energy density of food may have caused and/or aggravated the obesity dynamic, namely if the median indulges an unhealthy diet and is sufficiently poor.

The theory has been based on the assumption that the social norm is influenced by overweight of the median citizen. While it seems intuitively reasonable, that weight of the average person is an important determinant, it should be clear that nothing hinges on this assumption. In particular we could have assumed a “role model” less heavy than the median without qualitative impact on results. A more comprehensive assumption would certainly allow the social norm to depend on the whole bmi distribution. This assumption, however, would severely complicate the analysis and has been abandoned in favor of analytically provable results. The median has been imagined (implicitly) as the median of a country since most empirical studies are carried out at the country level or across countries. But in terms of theory, the type of the investigated society is actually undetermined. It is easily conceivable that the theory of obesity evolution applies to smaller societies than countries, that is at the level of local neighborhoods or among peers at school or at work.

Appendix

5.1. **Derivation of (23) and (24).** The Kuhn-Tucker conditions for a maximum of (22) can be simplified to

$$v_1 U_1 = 0, \qquad U_1 \equiv \alpha(\beta_1 - p_1)\left[1 - (s+\eta)(\epsilon_1 v_1 + \epsilon_2 v_2 - \mu) - \sigma v_1\right] \tag{A.1}$$
$$- (1-\alpha)\left[(s+\eta)\epsilon_1 + \sigma\right] \cdot \left[y + (\beta_1 - p_1)v_1 + (\beta_2 - p_2)v_2\right]$$

$$v_2 U_2 = 0, \qquad U_2 \equiv \alpha(\beta_2 - p_2)\left[1 - (s+\eta)(\epsilon_1 v_1 + \epsilon_2 v_2 - \mu) - \sigma v_1\right] \tag{A.2}$$
$$- (1-\alpha)(s+\eta)\epsilon_2 \cdot \left[y + (\beta_1 - p_1)v_1 + (\beta_2 - p_2)v_2\right].$$

Suppose that both $v_1 > 0$ and $v_2 > 0$. Solving the Kuhn-Tucker conditions for v_1 and v_2 provides:

$$v_1 = -\frac{N_1}{D}, \qquad v_2 = \frac{N_2}{D},$$
$$N_1 \equiv (\beta_1 - p_1)\left[1 + \mu(s+\eta)\right] + (s+\eta)\epsilon_1 y + \sigma y > 0$$
$$N_2 \equiv (\beta_2 - p_1)\left[1 + \mu(s+\eta)\right] + (s+\eta)\epsilon_2 y > 0$$
$$D \equiv (\beta_2 - p_2)\left[(s+\eta)\epsilon_1 + \sigma\right] - (\beta_2 - p_2)\epsilon_2(s+\eta).$$

Since both N_1 and N_2 are positive, sgn (v_1) = - sgn (v_2), a contradiction to the initial claim that both v_1 and v_2 are positive. Thus, either $v_1 = 0$ or $v_2 = 0$. Solving (A.1) for $v_2 = 0$ provides (23) and solving (A.2) for $v_1 = 0$ provides (24).

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