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Abstract

The empirical evidence of a non-monotone relation between income and obesity is not well explained. We build a theoretical model combining income inequality and social comparisons to explain the link between income and obesity and study tax policy implications for fighting obesity. We assume that differences in food consumption patterns between poor and wealthy households partly reflect positionality, which is the concern for social status. Our key assumption is that positionality for low-calorie food consumption is positively related to a country's wealth. In this framework, body weight outcomes reflect competing income and positionality effects, yielding the following results. We explain the link between average obesity rates, and standards of living and suggest the existence of a Kuznets curve for obesity. For cross sections of the population, we explain the observed correlation between income and obesity, which is positive in poor countries, and negative rich countries. We find that increasing the relative cost of high-calorie food is less effective at decreasing the relative weight of poor individuals in rich countries than in poor countries.

Keywords: Obesity, Status, Consumption Reference Points, Kuznets Curve, Tax Policy

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

1 Introduction

The first objective of this paper is to explain the link between income and obesity by building a theoretical growth model that combines income inequality and social comparisons. Understanding the link between income and obesity is essential to design adequate public policy addressing obesity related externalities. Therefore, the second objective of this paper is to study effective tax policies to fight obesity.

Indeed, obesity has been a major public health and public policy issue for several decades as it involves significant private and social costs. Private costs include increased mortality and morbidity risk. According to

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Mokdad et al. (2004 and 2005), obesity is the second leading cause of preventable death in the USA. Obesity is associated with a number of serious health risks including hypertension, dyslipidemia, type 2 diabetes, coronary heart disease, and some cancers. As a consequence, obese adults spend 42% more on health care costs than non-obese adults (Finkelstein et al, 2009). Obesity also imposes social costs. In the first place, obesity-related health care costs are estimated between $147 billion and nearly $210 billion per year in the USA (Cawley and Meyerhoefer, 2009, and Finkelstein et al. 2009). Parks et al. (2013) estimate that a one-unit increase in BMI for every adult in the United States increases annual public medical expenditures by $7.2 billion. As a consequence, non-obese individuals share the burden of obesity in the form of higher taxes (Parks et al., 2012) or insurance premiums (Bhattacharya and Bundorf, 2009). In the second place, obesity results in lower productivity, estimated at $506 per obese worker per year (Gates et al., 2008). For policymakers, addressing the issue of obesity is complicated by the fact that obesity prevalence is not uniform in society. On one hand, the empirical literature indicates that income and obesity can exhibit either a positive or a negative correlation. On the other hand, theoretical explanations of this complex link are limited. Tax policies implemented to fight obesity have so far experienced a lack of success. Our theoretical model provides a consistent explanation of the income-obesity link across countries and socioeconomic groups, and enables us to better understand the design of adequate tax policies.

There is a sizable empirical literature on the link between income and obesity. On one hand, there is evidence of a positive correlation between income and obesity. Schmeiser (2009) finds that 10 to 21 percent of the increase in women's BMI and 23 to 29 percent of the increase in women obesity prevalence is explained by the increase in real family income between 1990 and 2002 in the USA. Cawley's (2015) literature review also suggests evidence of a positive correlation between income and food consumption for adults in poor countries and for very low-income individuals in rich countries. For example, Fernald et al. (2008) show that doubling the payments of a conditional income transfer program in Mexico increases the risk of obesity in adults by 41 percent. Shapiro (2005) finds that food stamps recipients' recalled estimated calorie consumption falls by 0.40% each day after receipt of food stamps. Hastings and Washington (2010) find that the quantity of food purchased in Nevada's supermarkets by households declines 32% in the month following receiving food stamps or cash welfare. Mastrobuoni and Weinberg (2009) show that Social Security recipients with low retirement savings consume 24% fewer calories the week before receiving their Social Security check relative to the week afterward.

On the other hand, there is evidence of a negative correlation between income and obesity. Jo (2014) finds that there is a negative correlation between family income and childhood obesity. Sobal and Stunkard (1989) and McLaren (2012) find a negative correlation between weight and income among women but not among men. Ogden et al., 2010 finds that during the period 2005-2008, NHANES data indicate that the prevalence of obesity among adult women is 29.0% in households living 350% above the poverty line and 42.0% in households living below 130% of the poverty line.

Recent empirical studies suggest that there is a complex dynamic relation between income and obesity. Deuchert et al. (2014) show that average female body weight is higher in economically more advanced countries. While obesity is a problem concentrated on the socioeconomic elite in developing countries, its prevalence shifts toward individuals with lower socioeconomic status as economies develop. Grecu and Rotthoff (2015) find evidence of an obesity Kuznets curve for white females. As income increases, they consume more calories and obesity rates increase. However, at some point, while income continues to increase, obesity prevalence decreases.

Few theoretical contributions focus on the link between income and obesity. In Philipson and Posner's (1999) static model, technological change plays a central role to explain the rise in obesity and the link between income and obesity. In their model, technological change lowers the price of food, which explains the rise in obesity. The model predicts that weight gain is limited by the inverted U-shape effect of weight on utility. The effect of income on obesity changes from positive to negative with economic development, when rich individuals care more about their health and weight than poor individuals, and when there is some form of complementarity between consumption and weight. An inverted U-shape for the income-obesity link is obtained when the effect of consumption on the marginal dis-utility of weight gains is relatively higher for larger incomes. Lakdawalla et al. (2005) extend Philipson and Posner's (1999) model to account for the implications of technological progress on labor as an additional factor explaining the income-obesity relation. While technology-induced food price changes continue to play a central role in their model, they also argue that in rich countries, people are heavier than in poor countries because technological progress leads to more sedentary work. In rich countries, where work-place technology is more uniform, rich people are thinner than poor people because they assume that the demand for thinness is higher among rich individuals.

While technological progress and prices play an important role in the income-obesity relation, more work is needed to explain this complex relation. Indeed, despite the fact that the decline in food prices leveled off since the mid 1990's, average body weight and obesity have continued to increase. Burke and Heiland (2007) find evidence of shifting body weight norms to explain this phenomenon. The recent theoretical literature on food consumption behavior has developed to account for positionality, but this literature does not explain the complex link between income and obesity. Levy (2002, 2009) and Dragone (2009) present food consumption decisions as a rational intertemporal choice between food consumption and weight loss, abstracting from budget constraints. Individuals are positional with respect to a healthy weight norm but value food consumption and can be overweight in equilibrium. Dragone and Savorelli (2012), and Strulik (2014) focus on underweightness and assume that social stigma influences consumption decisions. Mathieu-Bolh (2018) shows that when individual's rational choice is influenced by heavier and heavier social weight norms, the obesity epidemic can be the result of social contagion.

To study the link between income and obesity, the empirical literature relies on data sets on disposable incomes. By contrast, in dynamic models, income reflects lifetime income. Lifetime income encompasses wages, productivity, and wealth in the form of capital ownership. Dynamic models capture the fact that an important distinction between poor and rich countries stems from differences in the per capita stock of capital, which, in equilibrium, yields differences in per capita production, or equivalently the standard of living. In the same way, distinctions between rich and poor individuals are tied to differences in wealth (capital ownership) or differences in productivity. Thus, when studying the link between income and obesity in our dynamic model, we will make the distinction between income differences related to wealth and differences related to productivity.

To explain the link between income and obesity, we make the assumption that differences in food consumption patterns between poor and wealthy households reflect a concern for social status. Specifically, we assume that expensive low-calorie food with high nutritional content, such as organic fresh fruit and vegetables or organic chicken is a positional goods as defined by Hirsh (1976): The consumption of those commodities signals individuals' rank in the social hierarchy. Furthermore, we connect society's changing average capital stock to positional food consumption behavior. Indeed, according to Veblen (1953, [1899]), as individuals become wealthier, they become conspicuous with respect to quality instead of quantity. Wealthy individuals' interest shifts away from materially valued products toward culturally valued products. Thus, the key mechanism of our model is that the degree of positionality (DOP) for low-calorie food consumption is positively related to the average stock of capital, and as a consequence, the preference for high-calorie food consumption is inversely related to the average stock of capital. Therefore, we assume that the DOP includes an endogenous component, while it is purely exogenous in the rest of the literature on food consumption behavior. Furthermore, connecting the DOP to the average capital stock enables us to better understand the link between obesity and income from both intertemporal and intratemporal points of view.

Our assumptions find relevance in the empirical literature. McCarthy (1977) shows that as income rises, people spend a portion of the increase on larger food quantities, but a large portion of the increase is spent on higher priced food varieties. Darmon and Drewnowski (2008) find that higher quality diets including whole grain, lean meats, fish, low-fat dairy products, and fresh fruit and vegetables are associated with high socioeconomic status, while energy-dense and nutrient-poor diets are associated with low socioeconomic status. Abbar et al. (2015) find that individuals with higher education levels tweet about food that is significantly less caloric. Palma et al. (2017) find evidence of food consumption driven by prestige to the point of becoming a symbol of social status.

The endogenization of the DOP is a fundamental difference between our framework and the past theoretical literature, in which preferences are exogenous. Indeed, in Philipson and Posner's (1999), and Lakdawalla et al. (2005), differences in preferences between rich and poor individuals are not related to social status and are purely exogenous. Furthermore, while those previous contributions relied on a static model, we propose a dynamic model, which enables us to clarify the roles of economic growth and inequality in the income-obesity relation.

Our work also builds upon the long standing literature on conspicuous consumption.[1] Specifically we extend the endogenous dynamic status preference model by Dioikitopoulos et al. (2017, 2018). We introduce two goods (low and high-calorie goods) and two types of individuals (poor and rich) in the model to describe individual food consumption behavior. The combination of the endogenous DOP with multiple goods and inequality is non-trivial and solving the problem requires us to use a procedure combining the methodologies by Fisher and Heijdra (2009), and Cantore and Levine (2012). Additionally, we connect food consumption behavior to body weight relying on the standard Schoefield (1985) equation. This framework enables us to explain the intertemporal relation between income and obesity.

Furthermore, our framework has important implications regarding food taxes and subsidies. We use it to describe the effect of taxing high-calorie food and subsidizing low-calorie food on body weight. So far, taxes have been implemented on energy-dense food with low nutritional content. Sugar-sweetened beverages taxes have been implemented in about two thirds of the United States. Canada, Denmark, Finland, France, Hungary, Norway, and Mexico have implemented some sorts of junk-food taxes. There is a sizable empirical literature exploring the effect of taxes on obesity. It provides a wide range of consumption elasticities and mixed evidence regarding the effect on obesity for the aggregate population (see literature reviews by Powell et al. 2013, and Cawley, 2015). One explanation is that, as a response to narrow-based taxes, individuals substitute the taxed good for other high-calorie goods that escape the tax (Fletcher, 2010 a,b). Another explanation is that taxes implemented so far may be too low to yield a significant change in the consumption of high-calorie food (Chaloupka et al., 2011, Fletcher et al., 2015). Empirical contributions also compare the effect of taxes on body weight outcomes of poor and rich individuals in industrialized countries. Compared to high income earners, Zhen et al. (2011) find that low income earners have a smaller own-price

[1] This literature grounded in the work by Smith (1759), Veblen (1899), and Duesenberry (1949), and also includes (but is not limited to) the contributions by Abel (1990), Gali (1994), Ireland (1994), Campbell and Cochrane (1999), Ljungquist and Uhlig (2000), Johanson-Stenman et al. (2002), Dupor and Liu (2003), Konrad (2004), Samuelson (2004), Liu and Turnovski (2005), Turnovski and Monteiro (2007), Wendner (2010 a, 2010 b), and Alvarez-Cuardo and Van Long (2012). It is also known as the literature on status, conspicuous consumption, or "keeping up with the Jones".

elasticity, but their cross price elasticity of demand for sugar-sweetened beverages is higher. Etile and Sharma (2015) also shows that high consumers of sugar-sweetened beverages have a less elastic demand for sugar-sweetened beverages than low consumers. Additionally, policy makers are concerned with potential adverse distributional effects of junk-food taxes. Thus, an ongoing debate is whether subsidies to low energy density food consumption (such as fresh fruits and vegetables) should be implemented on their own or combined with taxes on high energy density food consumption. For example, in 2012, the USDA conducted a pilot program offering SNAP recipients a 30% rebate on each dollar of benefits spent on fresh fruits and vegetables. The aforementioned literature reviews indicate that this type of intervention results in an increase in the purchase of low energy density food but evidence regarding body weight reduction is mixed. We provide insights on the effect of food taxes and subsidies on body weight outcomes in poor and rich countries and the differences in own-price demand elasticities between low and high income individuals. We shed light on the tax-subsidy debate by studying the effect of subsidies and the combined effect of taxes and subsidies on the body weight of poor and rich individuals in poor and rich countries.

Our main results are as follows.

- First, we explain the link between steady state average obesity rates and countries' standards of living. The effect of a higher steady state stock of capital on average body weight reflects two competing effects. The first effect is a standard income effect, which increases average body weight. The second effect is the dynamic positionality effect, which is unique to our model and decreases average body weight. We show that the income effect tends to be relatively large compared to the dynamic positionality effect in relatively poor countries, and it tends to be relatively small compared to the dynamic positionality effect in relatively rich countries. Thus, our results explain the positive correlation between income and obesity in poor countries as the result of a dominant income effect. They also suggest that rich countries may experience a slowdown in weight gain followed by a decrease in average body weight beyond a certain threshold of development as the result of a dominant dynamic positionality effect. Thus, the dynamic positionality effect suggests the existence of a Kuznets curve for obesity. While there is currently no decrease in the rate of obesity in the USA, the slowdown in the increase in obesity prevalence suggests that the USA may be getting closer to the tipping point of a Kuznets curve for obesity.[2] Our result is also consistent with Grecu and Rotthoff's (2015) empirical evidence of a Kuznets curve for obesity for white females.

- Second, we explain the link between the steady state relative body weight of individuals and their relative income in countries with different standards of living. We find that the relative body weight of

[2]See Figure 1 in the appendix.

an individual increases with her relative income (which includes relative wealth and relative productivity), decreases with the relative DOP when the relative energy density of high-calorie food exceeds its relative cost, and decreases with a country's average wealth. As a result, large inequality in wealth and productivity can potentially explain large differences between the low weight of poor individuals and the high weight of rich individuals in poor countries, where income is the main driver food consumption decisions. Differences in positionality can potentially explain large differences between the high weight of poor individuals and the low weight of rich individuals in rich countries, where positionality is the main driver of food consumption decisions.

- Third, we study the steady state effect on average body weight of taxes on high-calorie food consumption and subsidies to low-calorie food, in countries with low and high standards of living. We find that taxes on high-calorie food consumption is effective to lower average body weight in rich countries, but less effective in poor countries. This is explained by the fact that in rich countries, the negative income effect is enhanced by the dynamic positionality effect, which reinforces the relative distaste for high-calorie food. By reinforcing the rationale for taxing high-calorie food, our results echoes the concern that the lack of success of taxes to fight obesity in rich countries pertains to the fact that tax rates are too low and tax bases too narrow.[3] Our findings also points to the fact that subsidies to low-calorie food alone, while they improve nutritional contents of diets, are likely to increase average body weight in rich countries due to their positive income effect. Additionally, we study the effect of a one percent tax combined with a one percent subsidy, which aims at limiting adverse income effects associated with taxes used in isolation. We show that the effect of the policy on body weight depends on the relation between relative tastes, relative prices, and relative calorie intake. We find that when a tax is combined with a subsidy, the policy is less likely to result in a decrease in average body weight in rich countries compared to poor countries.

- Fourth, we study the steady state effect of increasing the relative cost of high-calorie food on the relative body weight of poor and rich individuals, in countries with low and high standards of living. In a given country, if relative positionality is very high, the tax policy is more effective at decreasing the relative weight of a relatively rich or a relatively more productive individuals than a relatively poor or a relatively less productive individuals. The reason is that the DOP reinforces the relative taste for low-calorie food compared to high-calorie food more among the relatively rich than the relatively poor. However, the richer a country, the less effective the tax policy is at reducing the relative body weight of an individual. Thus, we provide a potential explanation and a warning regarding the low own price

[3]See Powell et al.'s (2013) and Cawley's (2015) literature reviews.

elasticities of high-calorie food consumption among the poor and the limited success of tax policies on the body weight outcomes of poor individuals in rich countries.

The rest of the paper is organized as follows. In Section 2, we present the model. In Section 3, we present the comparative statics to explore the obesity income link, and in Section 4, we examine tax policy implications.

2 The Model

We modify the standard representative agent model to allow for three aspects. First, individuals derive utility from the consumption of two types of food, low-calorie food and high-calorie food. Second, households compare their own consumption to a reference point (the food basket of low- and high-calorie foods of their reference group). Third, the degree to which an individual considers the reference point important varies with his or her rank in the wealth distribution, and it may change over time, as a country develops.

Following Johansson-Stenman et al. (2002), we call the degree to which individuals consider the reference point important the degree of positionality (DOP). In our framework, individuals with differing ranks in the wealth distribution are considered to exhibit different DOPs. Specifically, we assume that, in a given country, at a given point in time, rich individuals care more for low-calorie food than poor individuals do. In other words, for a given level of development, as proxied by the per capita aggregate stock of capital, rich individuals care more about low-calorie food than poor individuals do and the DOP is higher for the rich than for the poor.

As in Dioikitopoulos et al. (2017, 2018), the DOP of a given individual is not exogenous but depends on the level of development of a country, captured by the per capita aggregate stock of capital. Over time, as individuals become wealthier and the per capita aggregate stock of capital increases, the DOP increases for all types of individuals and they become more positional with respect to healthy food. The DOP, while endogenous with respect to the per capita aggregate stock of capital, is exogenous to any individual when they make food consumption choices.

In our analysis, aggregate consumption and the composition of the respective consumption basket affects an individual's body weight gain. Following Yaniv et al. (2009), we assume that an individual does not take this into account when choosing a stream of consumption baskets over time.[4] Additionally, a deviation of the individual's body weight from the healthy weight norm reduces his or her utility.[5] In order to keep the

[4]Yaniv et al. (2009) consider the case of non-weight conscious and weight conscious individuals separately. The majority of empirical models assumes that individuals are not weight conscious, which means that they do not account for the effect of net calorie intake on body weight gain when making food consumption choices. Additionally, this assumption enables to describe budget constrained food consumption choices in a dynamic setting, while the alternative approach with weight conscious individuals allows for budget constraints in an intertemporal setting.

[5]By contrast, a social planner would take into account both the deviation of individual weight from the healthy weight norm as well as the impact of capital accumulation on an individuals's DOP. In this paper, we do not analyze normative issues such

analysis tractable, we refrain from population growth or technological progress and work with continuous time.

2.1 Households

There is a unit mass of individuals i. Each individual belongs to one of two types $i \in \{1, 2\}$ with respective masses $n^1 > 0$ and $n^2 > 0$, where $n^1 + n^2 = 1$. Type 1 (2) corresponds to low (high) productivity individuals, such that $\pi^1 < \pi^2$. Without loss of generality, we normalize productivity levels so that $n^1\pi^1 + n^2\pi^2 = 1$. Thus, the economy's average productivity level equals $\bar{\pi} = 1$. Each individuals inelastically supplies one unit of labor, for which she receives the type-specific wage rate $\pi^i w$. Initial wealth levels are given by (K_0^1, K_0^2), and K^i corresponds to individual *i's* wealth at time t. Since the model is written in continuous time, in the rest of the presentation, we eliminate time indexation.

2.1.1 Preferences

Let C_L^i and C_H^i respectively denote consumption of low-calorie and high-calorie food for individual i. Utility derived from a food basket (C_L^i, C_H^i) not only depends on the preference for own consumption, but also on a reference point involving low-calorie food consumption by peers: $\bar{C}_L$. That is, individuals care more for low-calorie food if their peers do so. By not specifying a reference point for high-calorie food, we simply imply that low-calorie food is *relatively* more important than high-calorie food for the formation of food reference points.[6] This level is common to all individuals. In particular, on a given date t, the DOP is higher for relatively wealthy type-2 than for (relatively poor) type-1 individuals. Both assumptions are well supported by substantive empirical evidence presented in the introduction.

Let K be the aggregate capital stock. Noting that we normalize the population size to equal unity, K is also the per capita stock of capital, and we employ K as an indicator of a country's development. Denoting an individual-i's DOP by function $\varepsilon^i(K)$, we assume two properties:

$$1 > \varepsilon^2(K) > \varepsilon^1(K) \geq 0\,, \quad K > 0; \tag{1}$$

$$\frac{\partial \varepsilon^i(K)}{\partial K} > 0\,, \quad i = 1, 2. \tag{2}$$

Property (1) states that for a given K, rich households care more for low-calorie consumption than poor households do. We call (1) the static positionality effect. As shown below, the static positionality effect helps

as optimal policy prescriptions.

[6]In principle, we could also introduce a reference point regarding high-calorie food. However, as we find that peer effects are stronger with respect to healthy low-calorie foods (e.g., organically grown vegetables, etc). Introducing only one reference point captures empirical evidence and sharpens our analytical results.

explaining the empirical fact that in many (developed) countries, obesity is less observed among wealthy than among poor individuals. Property (2) states that increasing development, as captured by per capita stock of capital K, raises all individuals' DOP, as is consistent with empirical evidence. This property accords with the empirical observation that, over time, as a county develops, households become on average more concerned with low-calorie food consumption. We call (2) the dynamic positionality effect.

An example satisfying assumptions (1) and (2) is given by:

$$\varepsilon^i(K) = 1 - e^{-\kappa^i K}, \quad \kappa^2 > \kappa^1 > 0\,, \quad i = 1, 2. \tag{3}$$

As is easily seen, $\varepsilon^i(0) = 0$, and $\partial\varepsilon^i(K)/\partial K > 0$, satisfying the dynamic positionality effect (2). Furthermore, for all (finite) $K > 0$, $\varepsilon^2(K) > \varepsilon^1(K)$, satisfying the static positionality effect (1). As $0 < K < \infty$, $0 < \varepsilon^i(K) < 1$ for all non-trivial steady-state values of per capita aggregate capital.[7]

In what follows, we distinguish consumption C_L^i from effective consumption $\hat{C}_L^i$:

$$\hat{C}_L^i = C_L^i - \varepsilon^i\,(K)\,\bar{C}_L. \tag{4}$$

If an individual does not care about others' low-calorie food consumption ($\varepsilon^i\,(K) = 0$), effective low-calorie consumption equals actual low-calorie consumption, and her utility solely depends on absolute consumption C_L^i. However, the higher $\varepsilon^i\,(K)$ is, the lower effective consumption of low-calorie food is, and the higher the marginal utility of C_L^i is.[8]

Each instant, an individual has preferences over effective consumption of the low-calorie food and absolute consumption of the high-calorie food. In particular, we specify instantaneous utility with a Cobb-Douglas function, implying that these two types of food can be substituted for each other. In addition, we note that a deviation of own individual body weight W^i from the healthy weight norm W^* lowers utility. Specifically, disutility from such a deviation is given by

$$\Delta^i = \frac{\beta}{2}\left(W^i - W^*\right)^2\,, \quad \beta > 0. \tag{5}$$

[7]Notice that this specification implies that $\partial\varepsilon^i(K)/\partial K$ declines in K. This is an arbitrary feature, however. Empirically, $\partial\varepsilon^i(K)/\partial K$ might not change much for some initial range $[0 < K < K_0]$, it might increase strongly for some intermediate range $[K_0 < K < K_1]$, and it might increase less strongly for some upper range $[K_1 < K < K_2]$, where $K_0 < K_1 < K_2$. Alternatively, if κ^i are small, then $\partial\varepsilon^i(K)/\partial K$ does not change much in K.

[8]This formulation is consistent with the literature on status preferences (keeping up with the Joneses). In that literature, C_L is called a "status good". We could also employ a multiplicative specification rather than the subtractive specification in (4), but this would not qualitatively change our analytical results.

Instantaneous utility is given by:

$$u^i(C_L^i, C_H^i) = \frac{\left[\left(\hat{C}_L^i\right)^{\alpha}\left(C_H^i\right)^{1-\alpha}\right]^{1-\theta}}{1-\theta} - \triangle^i, \quad 0 < \alpha < 1,\ \theta > 0. \tag{6}$$

Over time, an individual discounts instantaneous utility by a constant rate of time preference $\rho > 0$. The intertemporal utility function is:

$$\int_{t=0}^{\infty} u^i(C_L^i, C_H^i)\, e^{-\rho\tau} d\tau. \tag{7}$$

Each individual chooses consumption baskets, over time, to maximize (7) subject to its initial endowment of wealth K_0^i , and the flow budget constraint:

$$\dot{K}^i = rK^i + \pi^i w - \tilde{p}_H C_H^i - \tilde{p}_L C_L^i\ , \tag{8}$$

where $\tilde{p}_H$ and $\tilde{p}_L$ are the respective prices of a unit of high- and low-calorie foods, and subject to the No-Ponzi-Game (NPG) condition:

$$\lim_{\tau\to\infty} e^{-R(t,\tau)} K^i = 0, \tag{9}$$

where $R(t,\tau) = \int_t^{\tau} r(v)dv$.

2.1.2 Utility maximization

An individual takes the DOP, $\varepsilon^i(K)$, and the weight function, $\triangle^i\ (W^i, W^*)$, as given. Solving the individual's optimization problem involves using the present value Hamiltonian and deriving optimality conditions. The present-value Hamiltonian is:

$$\mathcal{H}^i = \left[\frac{\left[\left(\hat{C}_L^i\right)^{\alpha}\left(C_H^i\right)^{1-\alpha}\right]^{1-\theta}}{1-\theta} - \triangle^i\right] + \mu^i\left[rK^i + \pi^i w - \tilde{p}_H C_H^i - \tilde{p}_L C_L^i\ ,\right]$$

where the costate variable μ^i represents the shadow price of capital. We solve the individual's problem using a three-step procedure, which combines the method by Fisher and Heijdra (2009) and by Cantore and Levine (2012). The former accounts for positionality in consumption. It consists in maximizing utility with respect to effective consumption, and inferring optimality conditions for absolute consumption. The latter is based on a price index to account for multiple goods. Before proceeding, we define:

(i) $\widetilde{p} = \widetilde{p}_L^{\alpha}\tilde{p}_H^{1-\alpha}$, the price index;

(ii) $\tilde{p}C^i = \tilde{p}_H C_H^i + \tilde{p}_L C_L^i$, total actual food expense;

(iii) $\hat{C}^i = \left(\hat{C}_L^i\right)^\alpha \left(C_H^i\right)^{1-\alpha}$, total effective consumption in preferences;

(iv) $\tilde{p}\hat{C}^i = \tilde{p}C^i - \tilde{p}_L\varepsilon^i(K)\bar{C}_L$, total effective food expense;

(v) $p_L = \tilde{p}_L/\tilde{p}$; $p_H = \tilde{p}_H/\tilde{p}$, relative prices.

Given the definitions, we make use of the fact that total individual food expenditure is: $\tilde{p}_H C_H^i + \tilde{p}_L C_L^i = \tilde{p}C^i = \tilde{p}\hat{C}^i + \tilde{p}_L\varepsilon^i(K)\bar{C}_L$.

- In the first step of our procedure, we consider the dynamic optimization problem and express optimal effective consumption growth rates in the form of Euler equations. We re-write the present-value Hamiltonian as:

$$\mathcal{H}^i = \left[\frac{\left(\hat{C}^i\right)^{1-\theta}}{1-\theta} - \triangle^i\right] + \mu^i\left[rK^i + \pi^i w - \tilde{p}\hat{C}^i - \tilde{p}_L\varepsilon^i(K)\bar{C}_L\right].$$

The first order conditions are:

$$\frac{\partial \mathcal{H}^i}{\partial \hat{C}^i} = 0\,, \tag{10}$$

$$\frac{\partial \mathcal{H}^i}{\partial K^i} = \rho\mu^i - \dot{\mu^i}\,, \tag{11}$$

$$\lim_{\tau\to\infty} \mu^i(\tau)e^{-\rho\tau}K^i(\tau) = 0, \tag{12}$$

where (12) is the transversality condition. Given $\tilde{p}$, the growth rate of effective individual consumption is:

$$\frac{\dot{\hat{C}^i}}{\hat{C}^i} = \frac{1}{\theta}(r-\rho)\,. \tag{13}$$

This standard Euler equation reveals two important insights. First, effective consumption growth is the same for all individuals, reflecting the fact that the change in the DOP does not depend on individual wealth, but depends on the per capita aggregate stock of capital. This result enables the model to remain tractable. Considering the definition of total effective consumption, (13) does not generally imply that C_L^i grows at the same rate for all individuals. Second, in the steady state, $\dot{\hat{C}^i} = 0$. Thus, consumption positionality does not impact the steady state level of per capita aggregate capital.

- In the second step of our procedure, we consider the static optimization problem on a date t between the two consumption goods, effective low-calorie food consumption $\hat{C}_L^i$, and high-calorie food consumption C_H^i. Introducing the two food groups in the Hamiltonian yields:

$$\mathcal{H}^i = \left[\frac{\left[\left(\hat{C}_L^i\right)^\alpha \left(C_H^i\right)^{1-\alpha}\right]^{1-\theta}}{1-\theta} - \triangle^i\right] + \mu^i\left[rK^i + \pi^i w - \left(\tilde{p}_L\hat{C}_L^i\right)^\alpha \left(\tilde{p}_H C_H^i\right)^{1-\alpha} - \tilde{p}_L\varepsilon^i(K)\bar{C}_L\right].$$

The static first order conditions are:

$$\frac{\partial \mathcal{H}^i}{\partial \hat{C}_L^i} = 0, \tag{14}$$

$$\frac{\partial \mathcal{H}^i}{\partial C_H^i} = 0. \tag{15}$$

Considering, as in Cantore and Levine (2012), that at the optimum $\partial u^i/\partial \hat{C}_L^i = \mu^i \tilde{p}_L$ and $\partial u^i/\partial C_H^i = \mu^i \tilde{p}_H$, the ratio of optimality conditions (14) and (15) yields:

$$C_H^i = \frac{p_L}{p_H}\frac{1-\alpha}{\alpha}\hat{C}_L^i. \tag{16}$$

As a consequence, given p_L/p_H, C_H^i and $\hat{C}_L^i$ grow at the same rate.[9] Considering the definition of total effective consumption and the Euler equation (13), we obtain:

$$\frac{\dot{C}_H^i}{C_H^i} = \frac{\dot{\hat{C}}_L^i}{\hat{C}_L^i} = \frac{\dot{\hat{C}}^i}{\hat{C}^i} = \frac{1}{\theta}(r-\rho), \tag{17}$$

$$\frac{\dot{C}_L^i}{C_L^i} = \frac{1}{\theta}(r-\rho)\left[1 + \frac{\theta}{r-\rho}\frac{\bar{C}_L}{C_L^i}\left[\dot{\varepsilon^i}(K) + \dot{\varepsilon}\frac{\varepsilon^i(K)}{1-\varepsilon(K)}\right]\right], \tag{18}$$

where both $\dot{\varepsilon}(K)$ and $\dot{\varepsilon^i}(K) = \varepsilon^{i'}(K)\dot{K}$ are given for an individual.

Proposition 1: *In a growing economy ($r > \rho$), the dynamic positionality effect has two implications:*
(i) $\frac{\dot{C}_L^i}{C_L^i} > \frac{\dot{\hat{C}}_L^i}{\hat{C}_L^i} = \frac{1}{\theta}(r-\rho)$;
(ii) If positionality functions are similar across individuals: $C_L^j > C_L^i \Leftrightarrow \frac{\dot{C}_L^j}{C_L^j} < \frac{\dot{C}_L^i}{C_L^i}$, $i, j \in \{1, 2\}$, $i \neq j$.
Proof: *See Appendix.*

First, the proposition shows that the growth rates of low- and high-calorie food consumption differ solely due to the dynamic positionality effect. Without positionality considerations ($\varepsilon^i = 0, \varepsilon^{i'} = 0$), the growth rates of low- and high-calorie food consumptions would be identical. Second, the proposition shows that the growth rate of low-calorie food consumption depends on its level. Individuals who already have a high level of low-calorie food in their food basket choose a lower growth rate for low-calorie food consumption than individuals with a low level of low-calorie food do. As a consequence, for individuals of type i and j, the growth rates of low-calorie food consumption converge. This suggests that, at some point, the body weight gap between poor and rich individuals should be narrowing in rich countries.

- In the third step of our procedure, we derive optimal levels of low and high-calorie food consumption.

  Integrating the flow budget constraint (8) and imposing the NPG constraint (9), together with (17),

[9] Note that (16) is consistent with the definition of total effective food expenses. Equations (14) and (15) imply that $\mu^i \tilde{p}_L = \mu^i \alpha \hat{C}^i/\hat{C}_L^i$ and $\mu^i \tilde{p}_H = \mu^i (1-\alpha)\hat{C}^i/C_H^i$. Adding them up yields $\tilde{p}_L \hat{C}_L^i + \tilde{p}_H C_H^i = \alpha \hat{C}^i + (1-\alpha)\hat{C}^i = \hat{C}^i$.

we obtain by the standard procedure:

$$\tilde{p}_L \hat{C}_L^i + \tilde{p}_H C_H^i = \Omega \left[K^i + H^i - \mathit{\Gamma}^i \right] , \tag{19}$$

where $H^i(t)$ denotes human wealth, such that:

$$H^i(t) = \int_t^\infty e^{-R(t,\tau)} \pi^i w(\tau)\, d\tau ,$$

where $\Omega(t)$ represents the propensity to consume (which is the same across individuals), such that:

$$\Omega(t) = \frac{1}{\int_t^\infty e^{-R(t,\tau)+\frac{1}{\theta}\int_t^\tau (r(v)-\rho)dv} d\tau} ,$$

and $\mathit{\Gamma}^i(t)$ represents lifetime positionality, such that:

$$\mathit{\Gamma}^i(t) = \int_t^\infty e^{-R(t,\tau)} \tilde{p}_L \varepsilon^i (K(\tau)) \bar{C}_L(\tau)\, d\tau .$$

Substituting (16) and (4) into (19), we obtain individual i's absolute low-calorie consumption:

$$C_L^i = \frac{\alpha\Omega}{\tilde{p}_L} \left[K^i + H^i - \Gamma^i \right] + \varepsilon^i (K) \bar{C}_L. \tag{20}$$

Ceteris paribus (for given interest and wage rates) positionality has two opposing effects on low-calorie food consumption. One is a static effect denoted with the term $\varepsilon^i (K) \bar{C}_L^i$. Positionality results in individuals increasing low-calorie consumption to keep up with the Joneses. The other is a lifetime effect reflected in the term $\left[K^i + H^i - \Gamma^i \right]$. Given the propensity to consume Ω, positionality decreases lifetime wealth as more resources are allocated to low-calorie food consumption.[10] Absolute high-calorie consumption is:

$$C_H^i = \frac{(1-\alpha)\,\Omega}{\tilde{p}_H} \left[K^i + H^i - \Gamma^i \right] . \tag{21}$$

Ceteris paribus, positionality has only a negative effect on high-calorie food consumption through the negative effect of lifetime positionality on total lifetime wealth and consumption.

[10]The net effect of positionality on low-calorie consumption is not determined by (20). In addition, both Ω and $H^i$are forward-looking functions. Their magnitudes depend on the development of the rate of interest that are themselves affected by the consumption-saving choices of individuals.

2.2 Body Weight

Consumption and body weight are connected through the standard Schofield (1985) equation, in which we introduce the two food types. For an individual, weight gain $\dot{W}^i$ is a function of her net energy intake, the difference between energy intake and expenditure. Energy intake is a function of food consumption. Energy expenditure is a function of body weight W^i. The parameter $\lambda_L > 0$ represents the energy density of low-calorie food, and $\lambda_H > 0$ denotes the energy density of high-calorie food. By assumption, $\lambda_H > \lambda_L$. The parameter $\lambda > 0$ reflects the basal metabolic rate.

$$\dot{W}^i = \lambda_H C_H^i + \lambda_L C_L^i - \lambda W^i \, . \tag{22}$$

2.3 Firms

Competitive firms produce an output Y according to a neoclassical production function: $Y = F(K, L)$, where $L = \pi^1 L^1 + \pi^2 L^2$ is effective labor, L^1 and L^2 correspond to raw labor of respectively low- and high-productivity individuals, and K is the aggregate stock of capital. The production function $F(K, L)$ is homogeneous of degree one in (K, L). We consider labor supply to be exogenous.[11] Factors are paid their respective marginal products:

$$\frac{\partial F(K,L)}{\partial K} = r + \delta, \quad \frac{\partial F(K,L)}{\partial L^i} = \frac{\partial F(K,L)}{\partial L}\frac{\partial L}{\partial L^i} = w\pi^i, \quad i = 1, 2 \, , \tag{23}$$

where w denotes the efficiency wage.

Output can be used for either aggregate consumption or investment: $Y = \tilde{p}C + I$.

In a second step, a given level of aggregate consumption can be transformed into low- and high-calorie food consumption according to a linear production process, giving rise to the transformation frontier:

$$C - a_L C_L - a_H C_H = 0, \tag{24}$$

where the marginal rate of transformation of C_L for C_H is given by the ratio of production coefficients, a_L/a_H. Cost minimization implies $p_L/p_H = a_L/a_H$ for an interior solution. Considering the definition of the price index, $p_L^\alpha p_H^{1-\alpha} = 1$. Combining both yields: $p_H = (a_H/a_L)^\alpha \Leftrightarrow \tilde{p}_H = (a_H/a_L)^\alpha \tilde{p}$, and $p_L = (a_L/a_H)^{1-\alpha} \Leftrightarrow \tilde{p}_L = (a_L/a_H)^{1-\alpha}\tilde{p}$.

[11] The main reason for exogeneity of labor supply is to keep our analysis tractable.

2.4 Macroeconomic Equilibrium

In order to state the macroeconomic equilibrium, we need to define aggregate variables. An aggregate variable X relates to a type-i individual variable X^i and its weight n^i in the population, according to:

$$X \equiv \sum_{i=1}^{2} n^i X^i, \quad X \in \{C_L, C_H, C, K\}. \tag{25}$$

Recall that $n^1\pi^1 + n^2\pi^2 = 1$. Considering (8) and (25), $\dot{K} = n^1\dot{K}^1 + n^2\dot{K}^2 = rK + w - \tilde{p}_H C_H - \tilde{p}_L C_L = (r + \delta)K + wL - \tilde{p}C - \delta K$, with $L = 1$. As the production function is homogeneous of degree one, $\dot{K} = Y - \tilde{p}C - \delta K$.

Definition (Equilibrium) A competitive equilibrium is a price vector $(r, w, \tilde{p}_L, \tilde{p}_H, \tilde{p})$ and an attainable allocation for $t \geq 0$, such that:

1. Individuals choose feasible streams of C_L^i, C_H^i, K^i, so as to maximize intertemporal utility, given the price vectors, individual initial wealth endowments, productivities, the individual DOP, and aggregate capital.

2. Firms choose K^i and L^i in order to maximize profits, given the price vectors.

3. All markets clear. Specifically, $\dot{K} = Y - \tilde{p}C - \delta K$ (the goods market clear), $\sum_{i=1}^2 n^i K^i = K$ (the capital market clears), and $\sum_{i=1}^2 n^i L^i = 1$ (the labor market clears).

4. The aggregate consumption reference level equals $\bar{C}_L = \sum_{i=1}^2 n^i C_L^i = C_L$ in equilibrium.[12]

2.4.1 Macroeconomic Dynamics

The macroeconomic equilibrium gives rise to the following aggregate dynamics:

$$\dot{K} = F(K, L) - \tilde{p}C - \delta K, \tag{26}$$

$$\frac{\dot{C}_H}{C_H} = \frac{\dot{\hat{C}}_L}{\hat{C}_L} = \frac{\dot{\hat{C}}}{\hat{C}} = \frac{1}{\theta}(r - \rho), \tag{27}$$

$$\frac{\dot{C}_L}{C_L} = \frac{1}{\theta}(r - \rho) + \frac{\dot{\varepsilon}(K)}{\varepsilon(K)} \frac{\varepsilon(K)}{1 - \varepsilon(K)}, \tag{28}$$

$$\dot{W} = \lambda_H C_H + \lambda_L C_L - \lambda W, \tag{29}$$

$$\frac{\dot{\varepsilon}(K)}{\varepsilon(K)} = \underbrace{\frac{\varepsilon^{'}(K)K}{\varepsilon(K)}}_{\text{elasticity}} \frac{\dot{K}}{K}. \tag{30}$$

The growth rates of high-calorie, effective low-calorie, and effective aggregate consumption equal those of the individual growth rates, as these are the same across individuals. The growth rate of aggregate low-calorie

[12] This type of reference level is referred to as mean comparison in the literature on positional consumption. Alternative reference levels would be given by individual-specific reference levels or by upward comparisons (cf. Eckerstorfer and Wendner, 2013 for a discussion).

food consumption given by (28) differs from individual low-calorie food consumption and exceeds the growth rate of aggregate effective low calorie consumption (27).[13] The aggregate weight dynamics follows directly from individual weight dynamics. In (30), the first term on the right hand side denotes the elasticity of $\varepsilon(K)$ with respect to K.

Denote individual relative wealth by $k^i = K^i/K$ and individual relative consumption by $c^i = (\tilde{p}C^i)/(\tilde{p}C)$, where and $\tilde{p}C = \sum_{i=1}^{2} n^i(\tilde{p}_H C_H^i + \tilde{p}_L C_L^i)$. The individual wealth dynamics (k^i) can be derived by considering (8) together with the aggregate wealth dynamics:[14]

$$\dot{k}^i = \frac{w(K)}{K}(\pi^i - k^i) + \frac{\tilde{p}C}{K}(k^i - c^i). \tag{31}$$

Equation (31) shows that an individual's relative wealth may rise or decrease along transitional paths. In particular, the relative wealth of an individual is more likely to increase, the higher the productivity level compared to relative wealth and the higher relative wealth compared to relative consumption are.[15]

2.4.2 Steady-state equilibrium

In steady-state equilibrium, the economy verifies $\dot{K} = \dot{C} = \dot{C}_H = \dot{C}_L = 0$, so that all variables are stationary. Let the steady-state ratio of the marginal to average product of capital be given by $0 < \eta < 1$. Then, from (26) to (30), the following holds in a steady-state equilibrium. First, as $F_K(.) - \delta = r = \rho$,

$$K = F_K^{-1}(\delta + \rho), \tag{32}$$

where $F_K^{-1}(.)$ is the inverse function of the (monotone) marginal product function $F_K(.)$. Second, as $F_K(.) = \eta F(.)/K$:

$$F(.) = \frac{\delta + \rho}{\eta} K. \tag{33}$$

Third, from $\dot{K} = 0$, it follows that $\tilde{p}C = F(.) - \delta K$:

$$\tilde{p}C = \frac{\delta(1-\eta) + \rho}{\eta} K. \tag{34}$$

Thus, in steady state, neither aggregate capital nor consumption is affected by positional preferences or by the wealth distribution. However, the same does not hold for the transitional dynamics, the steady-state allocation of (C_H^i, C_L^i), the wealth distribution, and the weight distribution. The steady-state allocation of

[13] See Appendix for details.
[14] See appendix for details.
[15] Relative wealth dynamics (31) is formally equivalent to the one discussed in García-Peñalosa and Turnovsky (2008). In contrast to their model, c^i changes over time as individual and aggregate growth rates of low-calorie consumption differ.

(C_H^i, C_L^i) is clearly affected by the steady-state level of Γ^i. Using (31), we obtain that:[16]

$$k^i = c^i - \frac{(1-\eta)(\delta+\rho)}{\eta\rho}(\pi^i - c^i). \tag{35}$$

The intuition behind (35) is the following. Based on (31), $\dot{k}^i = \dot{k}^i(\underbrace{\pi^i}_{(+)}, \underbrace{c^i}_{(-)})$. For $\dot{k}^i = 0$, a rise in π^i must be compensated by a rise in c^i. In other words, in the steady state, for $\dot{k}^i, \dot{k}^j = 0$, $\pi^i > \pi^j$ requires $c^i > c^j$. However, this does not imply that individual i consumes more calories. As a consequence, both wealth inequality and positionality affect the cross-sectional weight distribution and the development of weight over time. Both aspects will thoroughly be analyzed below.

2.4.3 Relative Consumption, Wealth, and Body Weight

To be able to study a cross section of the population and compare poor and rich individuals' body weights, following Caselli and Ventura (2000), we express the relative body weight for type i individual. This requires to compare individual consumption and body weight to average consumption and body weight. Since in our model, the size of the labor force has been normalized to one, aggregate, per capita aggregate, and average variables are identical. In the rest of the paper, we use the term average, which is convenient to relate our results with empirical facts.

The representative consumer exhibits an average productivity $\pi = 1$, and a DOP $\varepsilon(K)$. As a result, average low and high-calorie consumption levels respectively are:

$$C_L = \frac{\alpha\Omega}{(1-\varepsilon(K))\,\tilde{p}_L}[K + H - \Gamma], \tag{36}$$

and:

$$C_H = \frac{(1-\alpha)\,\Omega}{\tilde{p}_H}[K + H - \Gamma], \tag{37}$$

where:

$$\dot{K} = rK + w - \tilde{p}_H C_H - \tilde{p}_L C_L, \tag{38}$$

$$H(t) = \int_{t=0}^{\infty} e^{-R(t,\tau)} w(\tau)\, d\tau,$$

$$\Gamma(t) = \int_{t=0}^{\infty} e^{-R(t,\tau)} \tilde{p}_L \varepsilon(K(\tau))\, C_L(\tau)\, d\tau,$$

[16]See Appendix for details.

and average body weight dynamics is given by:

$$\dot{W} = \lambda_H C_H + \lambda_L C_L - \lambda W \,. \tag{39}$$

Relative variables are denoted by lowercase letters x^i and $x^i = \frac{X^i}{X}$. Thus, relative body weight w^i is simply the ratio of individual over average body weight, thus,

$$\frac{\dot{w}^i}{w^i} = \frac{\dot{W}^i}{W^i} - \frac{\dot{W}}{W}.$$

We substitute (20), (21), into (22), and (36), (37) into (39), and noticing that in equilibrium $\mathit{\Gamma}^i/\mathit{\Gamma} = \gamma^i$, we re-express the dynamics of relative body weight as:

$$\begin{aligned} \dot{w}^i = & \left[\left(\lambda_H \frac{(1-\alpha)}{\alpha} \frac{1}{\tilde{p}_H} + \lambda_L \frac{1}{\tilde{p}_L} \right) \left((k+h)^i - w^i \right) \right] \frac{\alpha \Omega}{W} (K+H) \\ & + \left[\frac{\lambda_L \varepsilon(K)}{1-\varepsilon(K)} \epsilon^i(K) \right] \frac{\alpha \Omega}{W} (K+H-\Gamma) \\ & - \left[\left(\lambda_H \frac{(1-\alpha)}{\alpha} \frac{1}{\tilde{p}_H} + \lambda_L \frac{1}{\tilde{p}_L} \right) \left(\gamma^i - w^i \right) \right] \frac{\alpha \Omega}{W} \Gamma, \end{aligned} \tag{40}$$

where $\epsilon^i = \varepsilon^i/\varepsilon$, and $(k+h)^i$ denotes relative total wealth:

$$(k+h)^i = \frac{(K^i + H^i)}{(K+H)}.$$

Therefore, the evolution of relative body weight depends on three elements.

In (40), the first term denotes relative net caloric intake in the absence of social status. The net caloric intake depends on the difference between relative wealth and relative body weight. Relative wealth determines relative consumption and calorie intake, and relative body weight determines relative calorie expenditure.

The second term denotes the positive effect of relative positionality $\epsilon^i(K)$ on the propensity to consume out of modified average wealth $(K+H-\Gamma)$. The more positional individuals are, the higher their propensity to consume out of modified average wealth, the higher their net calorie intake. At the same time, the more positional individuals are, the smaller their lifetime modified average wealth and net calorie intake are. The third term denotes the negative effect of relative lifetime positionality γ^i compared to relative weight ω^i on net calorie intake. When relative lifetime positionality is larger (smaller) than relative weight, individuals have a relatively healthier (less healthy) diet and a relatively smaller (larger) relative caloric expenditure, which decreases (increases) relative weight gain. The overall effect of positionality on relative weight gain is therefore uncertain. In the next section, we clarify the effect of positionality on body weight outcomes relying on comparative statics.

The introduction of positional preferences has significant implications on the relative weight dynamics (40). Relative positionality and lifetime average and relative positionality change over time. As a result, relative weight gain is tied to capital accumulation and the induced change in relative positionality, as well as lifetime positionality and relative lifetime positionality. By contrast, if the degree of positionality were exogenous, relative positionality would be constant over time.

3 Comparative statics

The objective of this section is to explain empirical observations regarding body weight outcomes across countries and within countries for cross sections of the population.

3.1 Effect of average wealth on average body weight

To understand observed differences between poor and rich countries, we compare the steady state average body weight in countries with different average steady state stocks of capital.

Proposition 2: *In the steady state, a higher stock of capital yields a higher or a lower body weight. Body weight is higher (is lower) when the income effect is larger (smaller) than the dynamic positionality effect.*

Proof: See Appendix.

There are two ways to interpret Proposition 2. The dynamic interpretation is as follows. The steady state stock of capital reflects capital accumulation happening during the transition. Therefore, our dynamic model helps us understand why the link between income and obesity is tied to economic development. Indeed, individual's calorie consumption is determined by her income level and the endogenous DOP. Thus, as a country develops and accumulates capital, an individual's increase in calorie consumption is determined by an income effect in addition to the dynamic positionality effect (2). Combined, these two effects give rise to non-linear relationships between income and obesity. Over time, in a given country, the income effect tends to increase average food consumption. However, if the dynamic positionality effect dominates the income effect, the individual substitutes low-calorie food consumption for high-calorie food consumption, which may result in decreased calorie consumption and a reduction in body weight. Thus, our result explains the positive correlation between income and food consumption in poor countries as the result of a dominant income effect. Our result also suggests that rich countries may experience a slowdown in obesity prevalence, followed by a decrease beyond a certain threshold of development, as the result of a dominant dynamic positionality effect.

Our result is consistent with a Kuznets curve for obesity, as suggested by empirical evidence presented in the introduction.

The static interpretation is as follows. Comparing countries with different capital stocks, in the steady state, the average body weight is positively correlated to the level of the capital stock if the income effect is larger than the dynamic positionality effect. The average body weight is negatively correlated to the level of the capital stock if the dynamic positionality effect is larger than the income effect. In a poor country with a low capital stock, the income effect tends to be larger than the dynamic positionality effect. As a consequence, in the steady state, a higher capital stock results in a higher average body weight. Therefore, among poor countries, we expect to see a positive correlation between a country's level of development and the average body weight of the population. In rich countries with high capital stocks, beyond a certain threshold of economic development, the dynamic positionality effects may become larger than the income effect. Among rich countries, in the steady state, it is therefore possible to observe a positive or a negative correlation between a higher capital stock and average body weight.

Corollary 1: *If the DOP were exogenous, a higher steady state stock of capital would always result in a higher body weight.*

Proof: See Appendix.

Two countries may have different DOP for two reasons (see Section 2.1.1.). Either the exogenous component of their DOP related to sociocultural norms differs, or the endogenous component of their DOP related to the stage of their economic development differs. When the stock of capital increases, only the endogenous component of the DOP changes, which we describe as the dynamic positionality effect. Therefore, if the DOP were exogenous, as a country develops and accumulates capital, the individual's change in calorie consumption would solely be determined by the income effect and would increase. To endogenize the DOP is therefore key to reproduce observed differences regarding the income-obesity link between poor and rich countries.

Corollary 2: *When the stock of capital is low (high), a higher steady state stock of capital is more likely to yield a higher (lower) body weight if* $f''(K) < \varepsilon''(K)$.

Proof: See Appendix.

Corollary 2 sheds light on the conditions for the differences regarding the obesity income correlation between poor and rich countries to arise at one point in time. If the production function is more concave than the DOP function, for a low (high) stock of capital, the income effect is more likely to be larger (smaller) than the dynamic positionality effect, and body weight is more likely to increase (decrease). This condition potentially explains why in poor (rich) countries, the income-obesity correlation is positive (negative).

Taken together, the intertemporal- and cross-country implications of the dynamic positionality effect is that it generates a Kuznets curve for obesity. It explains why obesity is prevalent primarily in rich countries, and why under certain conditions, in poor countries, the income-obesity correlation is positive, while in rich countries, it is negative.

3.2 Effect of relative wealth, income, and positionality on relative body weight

To understand observed differences between poor and rich individuals in poor and rich countries, we compare individuals' steady state relative average body weights corresponding to different relative wealth, in countries with low or high average stocks of capital.

Proposition 3: *In the steady state, the relative body weight of an individual depends upon her relative productivity, relative wealth, relative DOP, the relative energy density of high-calorie food compared to the relative price of high-calorie food, and average positionality. Specifically, given an average stock of wealth:*

i) A higher relative wealth results in a higher relative body weight.

ii) A higher relative productivity results in a higher relative body weight.

iii) A higher relative static DOP results in a lower (higher) relative body weight, if the relative energy density of high-calorie food exceeds (is less than) its relative cost.

An individual relative body weight describes her ranking in the population with respect to body weight. Someone is relatively heavy (light) if they consume relatively more (less) high-calorie food than the average consumer and relatively less (more) low-calorie food than the average consumer. The relative consumption of high and low-calorie food depends on the individual's ranking with respect to her income, productivity, and DOP in the population.

Relative wealth does not influence positionality, only average wealth does. Therefore, given an average stock of wealth, there is no change in the DOP and no dynamic positionality effect. As a result, when relative wealth is high, the high relative equilibrium body weight solely reflects the income effect that yields a relatively high overall level of food consumption.

The DOP has two components. Besides the dynamic (endogenous) component, which depends upon average wealth, the DOP has a a static (exogenous) component, which relates to sociocultural norms.[17] An individual relative static DOP describes her ranking in the population with respect to the static component of the DOP. Relative body weight is tied to individuals' relative static DOP. Indeed, given an average stock of wealth, relatively more positional individuals consume a larger share of low-calorie food and weigh less than individuals who are relatively less positional. As a result, individuals with a higher relative static DOP

[17] See Section 2.1.1

have a relatively lower equilibrium body weight. This intuition holds as long as the relative energy density of high-calorie food exceeds its relative cost, which is generally the case.

Corollary 3: *In the steady state, large inequality in productivity and wealth tend to increase weight dispersion, while large inequality in positionality tends to limit body weight dispersion.*

Proof: See Appendix.

Corollary 4: *In the steady state, the relative body weight of an individual is inversely related to the country's average stock of capital.*

Proof: See Appendix.

When the average stock of capital is higher, relative individual wealth is lower. As a consequence, a lower relative wealth yields a lower relative level of food consumption. At the same time, the average stock of capital increases individual's positionality through the dynamic positionality effect and the relative share of low-calorie food in total consumption increases. As a consequence, in the steady state, overall calorie consumption is relatively lower and relative body weight is relatively lower.

Thus, corollaries 3 and 4 suggest that economic development and inequality play a role in explaining body weight dispersion in the population. In a poor country with a low stock of capital, the income level is the main determinant of food consumption choices. When individuals become relatively richer, they can afford to purchase more low and high-calorie food. As a consequence, relatively richer individuals consume more calories and weigh more than relatively poor individuals. As a result, large inequality in productivity and wealth can potentially explain large differences between the low relative weight of poor individuals and the high relative weight of rich individuals in poor countries. In a rich country with a high stock of capital, the concern for social status described by the DOP is the main determinant of food consumption choices. When individuals become relatively richer, they are more attracted to relatively expensive low-calorie food as a symbol of social status. While individuals' total calorie consumption increases due to the income effect, the dynamic positionality effect dominates and they increase the share of low-calorie food consumption in their diet, which results in a lower relative steady state body weight. This phenomenon is exacerbated by the exogenous component of the DOP if there is inequality. As a result, inequality in positionality coming from the endogenous component of the DOP (the average stock of capital) or the exogenous component of the DOP (sociocultural norms) can potentially explain large differences between the high relative weight of relatively poor individuals and the low relative weight of relative rich individuals in rich countries. Therefore, Corollaries 3 and 4 provide a rational to explain observed differences between poor and rich countries regarding the income-obesity relation for cross sections of the population.[18] Table 1

[18]The specific roles of inequality on body weight outcomes and its interaction with positionality are studied in more depth in a subsequent paper.

summarizes the main results of Section 3.

[Table 1 here]

4 Tax Policy implications

The objective of this section is to better understand the effect of food taxes and subsidies on steady state body weight outcomes. We make the standard assumption that a one percent change in a tax (subsidy) on a consumption good yields a one percent increase (decrease) in the price of that good.[19]

4.1 Effect of relative price changes on average body weight

In this subsection, we focus on understanding policy outcomes in poor and rich countries. First, we study the steady state effect of a tax on high-calorie food, keeping the price of low-calorie food unchanged. Second, we study the effect of a subsidy to low-calorie food, keeping the price of high-calorie food unchanged. The results are presented in Proposition 4. Third, we study the effect of a tax on high-calorie food, combined with a subsidy to low-calorie food. The result is presented in Proposition 5. We compare the outcome of those different policies in countries with low or high average stocks of capital and present results in Corollaries 5 and 6.

Proposition 4: *A tax on (subsidy to) high (low) calorie food always results in a lower (higher) average body weight in the steady state.*

Proof: See Appendix.

In the steady state, a higher (lower) relative cost of high (low) calorie food yields lower consumption of high (low) calorie food. In the steady state, the cross price elasticity of effective low (high) calorie food consumption equals zero. As a result, individuals consume fewer (more) calories and average body weight is lower (higher). It is important to notice that during the transition to the steady state, the cross price elasticity of effective low-calorie food consumption is different from zero. This implies that a tax (subsidy) is likely to reduce (increase) body weight less in the short compared to the long run. While this observation is tied to the functional form of the utility function, it suggests that in some circumstances, it may take time before tax policies yield their full effects on body weight.[20]

To understand the respective roles of income and positionality, we compare a poor and a rich country.

Corollary 5: *A tax on high-calorie food is likely to result in a relatively smaller (larger) decrease in steady*

[19] See e.g. Yaniv et al. (2009), and Mathieu-Bolh (2010 and 2017).

[20] Transitional effects of food taxes and subsidies are addressed in another paper.

state body weight in a poor (rich) country. A subsidy to low-calorie food is likely to result in a relatively smaller (larger) increase in steady state body weight in a poor (rich) country.

Proof: See Appendix.

Following a subsidy to low-calorie food, the higher (lower) the DOP, the higher (lower) the consumption level of low-calorie food. Indeed, in countries with high (low) capital stocks, the status effect is large (small), which yields a large (small) relative taste for low-calorie food. A subsidy causes a positive income effect, which yields an increase in individual overall food consumption, including a relatively large (small) increase in low-calorie food consumption, and a large (small) increase in average body weight. In the same way, following a tax on high-calorie food, the higher (lower) the DOP, the larger (smaller) the decrease in the consumption of high-calorie food. In countries with high (low) capital stocks, the status effect is large (small), which yields a large (small) relative distaste for high-calorie food. A tax causes a negative income effect, which yields a decrease in individual overall food consumption, including a large (small) decrease in high-calorie food consumption, and a large (small) decrease in average body weight. Thus, when the stock of capital is high (low), the own price elasticities of high-calorie food and low-calorie food are high (low). As a consequence, the response of body weight to taxes and subsidies is larger in rich countries than in poor countries in the steady state.

Proposition 4 and corollary 5 suggest that in rich countries, taxing high-calorie food should be an effective tool to reduce the consumption of high-calorie food. Therefore, these policies appear as effective tools to improve nutritional quality of diets in rich countries. These policies appear as a less effective tool to improve nutritional quality of diets or fight obesity in poor countries than in rich countries.

Proposition 5: *In the steady state, a one percent tax on high-calorie food combined with a one percent subsidy to low-calorie food results in a higher or lower steady state body weight depending on the relation between the DOP, relative prices, and relative calorie intake. The policy results in a lower body weight if* $\frac{\gamma_L}{\gamma_H}\frac{\alpha}{(1-\alpha)(1-\varepsilon(K))} < \frac{\tilde{p}_L}{\tilde{p}_H}$*, and a higher body weight otherwise.*

Proof: See Appendix.

Corollary 6: *When the stock of capital is low (high), a one percent increase in the price of high-calorie food combined with a one percent decrease in the price of low-calorie food is more (less) likely to result in a lower steady state body weight.*

Proof: See Appendix.

Proposition 5 and corollary 6 provide a potential explanation and a warning regarding the lack of success of a tax-subsidy mix aiming at reducing obesity in rich countries. A one percent increase in the price of high-calorie food combined with a one percent increase in the price of low-calorie food is likely to limit adverse income effects but not eliminate them as initial prices and consumption shares differ for low and high-calorie food. We consider that changes in relative prices result in income and positionality effects. In a poor country, the stock of capital and the DOP are low. As a consequence, average individuals tend to consume a lot of high-calorie food relatively to low-calorie food. The policy change is likely to result in a negative income effect, which decreases their overall food consumption, and yields a small relative decrease in the consumption of high-calorie food in the steady state due to the positionality effect. Both the negative income effect and the positionality effect result in a lower steady state body weight. In a rich country, the stock of capital and the DOP are high. As a consequence, average individuals tend to consume a lot of low-calorie food. The policy change is likely to result in a positive income effect, which increases their overall food consumption, and yields a large relative increase in low-calorie food consumption due to the positionality effect. The net effect can be a lower steady state body weight when the status effect is large enough and a higher steady state body weight when the income effect is large enough. Table 2 summarizes the main results of Section 4.1.

[Table 2 here]

4.2 Effect of relative price changes on relative body weight

In this subsection, we focus on understanding policy outcomes for poor and rich individuals in poor or rich countries. We study the effect of a higher relative cost of high-calorie food on relative body weight in the steady state, which could come from a tax on high-calorie food or a subsidy to low-calorie food (Proposition 6). We compare the effect of a higher cost for high-calorie food relative to low-calorie food on the relative weight of individuals, based on their relative wealth, productivity, and positionality (Corollary 7). Furthermore, we compare the outcome of this policy in countries with low or high average stocks of capital (Corollary 8).

Proposition 6: *In the steady state, assuming the depreciation rate is zero, if an individual relative income is smaller (larger) than her relative positionality, a higher relative cost of high-calorie food results in a lower (higher) relative body weight in the steady state.*

Proof: See Appendix.

An individual relative income, represents her ranking in society with respect to her total income. It encompasses her ranking with respect to productivity and wealth. If the individual is more (less) positional than the average individual and this effect dominates (is dominated by) the effects of relative income, her relative body weight decreases (increases) when the relative cost of high calorie food increases. The reason is as follows. An individual is relatively light (heavy) if they consume relatively less (more) high-calorie food than the average consumer and relatively more (less) low-calorie food than the average consumer. An individual who is relatively richer (poorer) can afford and consume (less) more food than the average consumer due to the income effect. However, when the individual is more (less) positional than the average, her consumption of high-calorie food decreases (increases) compared to the average consumer and her consumption of low-calorie food increases (decreases) compared to the average consumer. As a result, when the relative positionality effect dominates (the relative productivity and wealth effect dominates), the effect of an increase in the cost of high calorie food is a decrease (an increase) in calorie intake relative to the average consumer.

Corollary 7: *The increase in the relative cost of high-calorie food is more (less) effective at reducing her relative body weight for:*

i) A relatively rich (poor) individual, if her relative positionality is larger than the average wealth income.

ii) A relatively more (less) productive individual, if her relative positionality is larger than the average labor income.

iii) An individual with a relatively higher (lower) static DOP.

Thus, in a given country, if relatively rich or productive individuals are relatively positional, the increase in the relative cost of high-calorie food results is an increase in relative low-calorie food intake compared to relative high-calorie food intake, which results in a larger relative weight loss. Therefore, within a country, relatively poor or low productive individuals who are relatively less positional are less responsive to the tax policy compared to relatively rich or productive individuals.

Corollary 8: *The effectiveness of the increase in the relative cost of high-calorie food at reducing the relative body weight of an individual is inversely related to a country's average stock of capital, if the individual's relative positionality is larger than the contribution of capital intensity to the country's average income.*

Proof: See Appendix.

Contrary to Corollary 7, where the high relative degree of positionality is due to differences in sociocultural norms (the static component of positionality), in this case, the high relative degree of positionality is tied to the high level of average capital (the dynamic component of positionality). If the high level of average capital results in the relative DOP of an individual being high compared to the contribution of capital intensity to the country's average income (α), the tax policy is less effective at reducing her relative body weight. Indeed, in a rich country, the negative income effect of a tax could be partially offset by the high relative DOP. The decrease in overall food consumption could be partially offset by a very large increase in low-calorie food consumption.

Corollary 7 is consistent with the empirical observation that, in the USA, the price elasticity of junk food is lower for relatively poor individuals compared to relatively rich individuals. Combined with Corollary 8, these results provide a rationale for the lack of success of tax policies in rich countries, such as soda taxes, aiming at reducing body weight among relatively poor households. Table 3 summarizes the main results of Section 4.2.

[Table 3 here]

5 Conclusions

This paper provides a dynamic framework – involving consumption of low- and high-calorie foods – for understanding the complex relationship between income and obesity. The paper considers the following important dimensions: income and obesity within a country over time, and cross-sectional income and obesity at a given point in time, both within a country and between countries. Empirical evidence does not point to a monotone relationship in either of these cases but is instead consistent with the following observations. First, over time, in a given country, as income increases, obesity prevalence increases rapidly, then slows down, and in some cases declines (obesity Kuznets curve). Second, in a cross-section of countries, average obesity is high in rich countries and low in poor countries, at a given point in time. Third, obesity prevalence is relatively high among poor individuals in rich countries and among rich individuals in poor countries.

Our framework provides possible explanations of these empirical facts by accounting for social comparisons. Households compare their own consumption to a reference point, which is the high-quality low-calorie food consumption level of their reference group. The degree to which an individual considers the reference point important varies with average income and changes over time, as a country develops, and capital accumulation yields a higher average income. Social comparisons add static and dynamic positionality effects to the usual income and substitution effects which help explaining empirical facts.

Over time, as a country develops, the income effect raises expenditure for average food consumption, and therefore calorie intake increases. However, the dynamic status effect makes low-calorie food more attractive compared to high-calorie food, which tends to lower calorie intake. If the dynamic status effect dominates the income effect, individuals will substitute low-calorie foods for high-calorie foods, resulting in decreased calorie consumption and a reduction in average obesity rates. Such a situation is consistent with a Kuznets curve for obesity, as suggested by data.

Across countries, at a given point in time, the degree of positionality is low in poor countries and high in rich countries due to differences in the average capital stock. The endogenous degree of positionality implies that the diet is more directed towards high-calorie foods in poor than in rich countries. At the same time, due to low income, total calorie consumption is limited in poor countries, while the opposite holds for rich countries. As long as the income effect dominates the dynamic positionality effect, obesity prevalence is increasing with the average capital stock. This result is consistent with the observation that obesity prevalence is primarily seen in rich countries. It also suggests that beyond a certain threshold of development, if the dynamic positionality effect dominates the income effect, we could observe a negative correlation between income and obesity among some rich countries.

Within a country, at a given point in time, given the average capital stock, the static positionality effect implies that individuals with low socioeconomic status are less concerned with low-calorie food than those with high socioeconomic status. If this static positionality effect dominates the income effect, obesity is seen among poor individuals more than among rich ones, as is consistent with data about rich countries. The opposite holds for poor countries. Combining our cross- and within-country results, we find that differences in positionality coming from differences in average stocks of capital between countries and sociocultural norms within countries explain that obesity is more prevalent among the poor in rich countries and among the rich in poor countries.

Our framework has significant policy implications. A tax on high-calorie food is less effective at reducing average body weight in rich than in poor countries, and a subsidy to low-calorie food increases body weight in rich countries more than in poor countries. Moreover, a combined tax-subsidy scheme produces ambiguous effects on the average body weight. Specifically, upon introduction of the tax scheme, body weight is likely to increase (decrease) in rich (poor) countries, due to the different composition of food baskets (low-to-high-calorie food) among rich and poor countries. While in poor countries, both the substitution and negative income effect decrease body weight, in rich countries, the positive income effect (due to a relatively high share of low-calorie foods) may dominate the substitution effect and lead to a rise in body weight. Such a policy might therefore not be effective in rich countries, if the focus is to decrease the average body weight. Finally, tax policy raising the relative price of high-calorie food reduces the relative body weight of an individual - however more so for the rich than the poor, and less so in rich countries compared to poor countries. The main reason stems from the different roles of the endogenous and exogenous components of the DOP. The endogenous component of the DOP relates to the average capital stock and provides a buffer mechanism against the negative income effects of taxation. The exogenous component of the DOP relates to different sociocultural norms and accentuates the effect of tax policies.

We recognize the following limitations in our analysis. First, although there are differences in obesity patterns between men and women within income groups, our framework does not distinguish between men and women. Second, our analysis is restricted to comparative statics, and the chosen utility function maintains tractability but yields cross price elasticities equal to zero in the steady state. As a consequence, our paper does not explore differences between short-run and long-run effects of tax policies on obesity. Third, our paper does not address normative issues. Such issues could include optimal policies derived by a social planner taking into account the impact of food choices on the deviation of individual from optimal weight, or the impact of capital accumulation on the DOP. Fourth, our paper does not further investigate the relationship between inequality and the degree of positionality. These limitations define important future research questions. Notwithstanding these limitations, our theory provides an explanation and a better understanding of the mechanism driving the non-monotone relation between income and obesity, and delivers important insights on tax policy outcomes.

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6 Figures

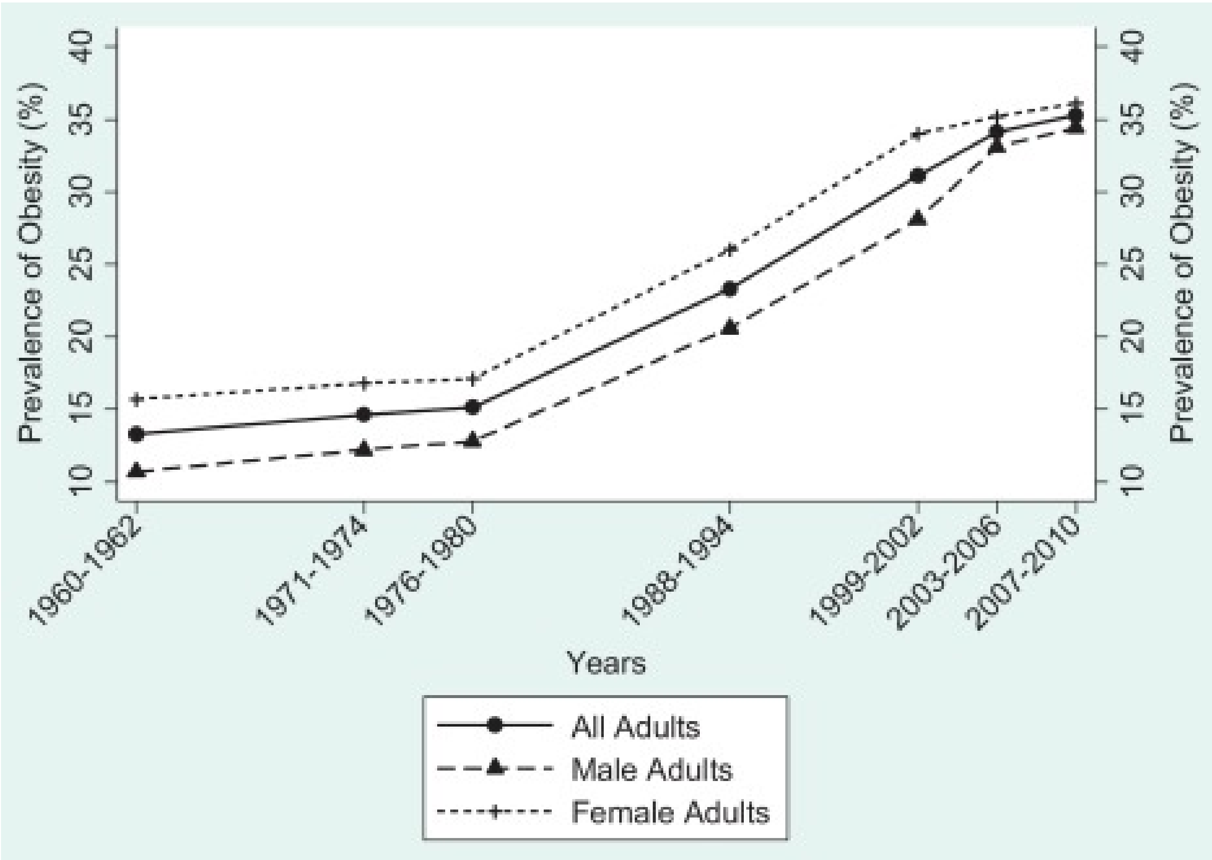

Figure 1: Slowdown in the prevalence of obesity in the USA.

Source: Cawley (2015)

7 Tables

Table 1. Impact of average and relative capital (wealth) on average and relative body weight

Proposition 2.	$K^A < K^B$	$K \uparrow$	Empirical Evidence & Results
DPE=0	$W^A < W^B$	$W \uparrow$	Non-monotone relationship between capital (wealth) and body weight; Kuznets curve for obesity
IE $>$ DPE	$W^A < W^B$	$W \uparrow$	
IE $<$ DPE	$W^A > W^B$	$W \downarrow$	
Proposition 3.	(i) $k^i > k^j$	(ii) $\epsilon^i(K) > \epsilon^j(K)$	
	$w^i > w^j$	$w^i < w^j$	Poor countries (low K): obesity prevalent mostly among rich people; Rich countries (high K): obesity prevalent mostly among poor people
Low K	(i) dominates (ii)		
High K	(ii) dominates (i)		

Notes. K = average wealth, k^i = relative wealth, DPE = dynamic positionality effect, IE = income effect. A and B can be interpreted either as two countries or as one country in which the steady state level of K changes from K^A to K^B due to structural changes.

Table 2. Rich and poor countries and the impact of taxes/subsidies on average body weight

Proposition 4.	$\tau_{C_H} > 0$	$\tau_{C_L} < 0$	Policy Implications
	$W \downarrow$	$W \uparrow$	Less effective in short-run than in long-run
low K	small impact on W		
high K	large impact on W		
Proposition 5.	$(\tau_{C_H} > 0) \wedge (\tau_{C_H} > 0)$		Policy Implications
low K	$W \downarrow$		Effectiveness of tax/subsidy mix is limited in rich countries
high K	$W \uparrow$		

Notes. $\tau_{C_H} > 0$ is a tax on high-calorie consumption, $\tau_{C_L} < 0$ is a subsidy on low-calorie consumption. Low (high) K refer to a situation in which $\varepsilon(K)$ is less than (exceeds) $1 - (\tilde{p}_H/\tilde{p}_L)(\gamma_L/\gamma_H)(\alpha/(1-\alpha))$.

Table 3. Wealth distribution, relative positionality, and effectiveness of public policy on obesity

Proposition 6.	$(\tilde{p}_H/\tilde{p}_L)\uparrow$	Policy Implications
$y^i, k^i, \pi^i < \epsilon^i(K)$	$w^i \downarrow$	Even for high $\epsilon^i(K)$, a tax policy aiming at a reduction in obesity is less effective for relatively poor and less productive individuals. Tax policy is less effective in rich than in poor countries.
$y^i, k^i, \pi^i > \epsilon^i(K)$	$w^i \uparrow$	
$\epsilon^i > \alpha$, k^i high	$w^i \downarrow$ effective	
$\epsilon^i > \alpha$, k^i low	$w^i \downarrow$ ineffective	
$\epsilon^i > 1-\alpha$, π^i high	$w^i \downarrow$ effective	
$\epsilon^i > 1-\alpha$, π^i low	$w^i \downarrow$ ineffective	
$\epsilon^i > \alpha$, high K	$w^i \downarrow$ ineffective	
$\epsilon^i > \alpha$, low K	$w^i \downarrow$ effective	

Notes. The results in this table refer to the case $\delta = 0$, and the term y^i denotes relative income.

8 Appendix

8.1 Proof of Proposition 1.

Considering (4) and (17), for an individual of type i:

$$\frac{r-\rho}{\theta} = \frac{\dot{C}_L^i}{C_L^i}\frac{C_L^i}{C_L^i - \varepsilon^i(K)\bar{C}_L} - \frac{\frac{d}{dt}\left[\varepsilon^i(K)\bar{C}_L\right]}{C_L^i - \varepsilon^i(K)\bar{C}_L}. \tag{41}$$

We aim at comparing $\frac{\dot{C}_L^i}{C_L^i}$ with $\frac{\dot{\hat{C}}_L^i}{\hat{C}_L^i} = \frac{r-\rho}{\theta}$. Based on (41), we can simply write that: $\frac{\dot{C}_L^i}{C_L^i} = x\frac{\dot{\hat{C}}_L^i}{\hat{C}_L^i} = x\frac{r-\rho}{\theta}$ for some $x > 0$. The case of interest is whether x is smaller than, or equal to, or grater than unity. We re-write the above equation as

$$\frac{r-\rho}{\theta} = x\frac{r-\rho}{\theta}\frac{C_L^i}{C_L^i - \varepsilon^i(K)\bar{C}_L} - \frac{\frac{d}{dt}\left[\varepsilon^i(K)\bar{C}_L\right]}{C_L^i - \varepsilon^i(K)\bar{C}_L},$$

or,

$$\frac{r-\rho}{\theta}\left[1 - \frac{xC_L^i}{C_L^i - \varepsilon^i(K)\bar{C}_L}\right] = -\frac{\frac{d}{dt}\left[\varepsilon^i(K)\bar{C}_L\right]}{C_L^i - \varepsilon^i(K)\bar{C}_L} \Leftrightarrow \frac{r-\rho}{\theta}\left[1 - \frac{C_L^i(1-x)}{\varepsilon^i(K)\bar{C}_L}\right] = \frac{\dot{\overline{\varepsilon^i(K)}}}{\varepsilon^i(K)} + \frac{\dot{\bar{C}}_L}{\bar{C}_L}. \tag{42}$$

To find $\dot{\bar{C}}_L/\bar{C}_L$, we use (42), and set $C_L^i = \bar{C}_L$ and $\varepsilon^i = \bar{\varepsilon}$, which yields:

$$\frac{r-\rho}{\theta} = \frac{\dot{\bar{C}}_L}{\bar{C}_L}\frac{\bar{C}_L}{\bar{C}_L - \bar{\varepsilon}(K)\bar{C}_L} - \frac{\frac{d}{dt}\left[\bar{\varepsilon}(K)\bar{C}_L\right]}{\bar{C}_L - \bar{\varepsilon}(K)\bar{C}_L},$$

After some manipulation, this expression becomes

$$\frac{\dot{\bar{C}}_L}{\bar{C}_L} = \frac{r-\rho}{\theta} + \frac{\bar{\varepsilon}(K)}{1-\bar{\varepsilon}(K)}\frac{\dot{\bar{\varepsilon}}(K)}{\bar{\varepsilon}(K)}. \tag{43}$$

Considering (43) in (42) yields:

$$x = 1 + \frac{\theta}{r-\rho}\frac{\bar{C}_L}{C_L^i}\underbrace{\left[\dot{\varepsilon}^i(K) + \dot{\bar{\varepsilon}}\frac{\varepsilon^i(K)}{1-\bar{\varepsilon}(K)}\right]}_{\equiv E^i > 0} = 1 + \frac{\theta}{r-\rho}\frac{\bar{C}_L E^i}{C_L^i} > 1. \tag{44}$$

That is, $\frac{\dot{C}_L^i}{C_L^i} > \frac{\dot{\hat{C}}_L^i}{\hat{C}_L^i} = \frac{r-\rho}{\theta}$ for all i.

Consider two individuals $i$and j, with $C_L^j > C_L^i$. If $E_L^j < (C_L^j/C_L^i)E_L^i$, then $\frac{\dot{C}_L^i}{C_L^i} > \frac{\dot{C}_L^j}{C_L^j}$. The restriction ensures that E^i and E^j are similar to each other: E^j must either be smaller than E^i, or not exceed E^i by too much. This proves (ii) of Proposition 1. ■

8.2 Aggregate growth rate of low-calorie consumption

We notice that:

$$\frac{\dot{C}_L}{C_L} = \frac{n^1 C_L^1}{C_L}\frac{\dot{C}_L^1}{C_L^1} + \frac{n^2 C_L^2}{C_L}\frac{\dot{C}_L^2}{C_L^2}.$$

Observing that $\bar{\varepsilon}(K) = n^1\varepsilon^1(K) + n^2\varepsilon^2(K)$, $\dot{\bar{\varepsilon}}(K) = n^1\dot{\varepsilon}^1(K) + n^2\dot{\varepsilon}^2(K)$, and $n^1C_L^1 + n^2C_L^2 = C_L$, and using the individual low-calorie consumption growth rates (18), as derived in the proof of Proposition 1, yields:

$$\frac{\dot{C}_L}{C_L} = \frac{1}{\theta}(r-\rho) + \frac{\dot{\bar{\varepsilon}}(K)}{\bar{\varepsilon}(K)}\frac{\bar{\varepsilon}(K)}{1-\bar{\varepsilon}(K)}.$$

■

8.3 The individual wealth dynamics, and individual wealth in the steady state

As $k^i = K^i/K$, $\dot{k}^i/k^i = \dot{K}^i/K^i - \dot{K}/K$. Equation (8) implies

$$\frac{\dot{K}^i}{K^i} = r + \frac{\pi^i}{k^i}\frac{w}{K} - \frac{\tilde{p}C^i}{K}\frac{1}{k^i}. \tag{45}$$

The aggregate capital dynamics is given by:

$$\frac{\dot{K}}{K} = r + \frac{w}{K} - \frac{\tilde{p}C}{K}. \tag{46}$$

Subtracting (46) from (45), multiplying with k^i and observing that $c^i = (\tilde{p}C^i)/(\tilde{p}C)$ yields

$$\dot{k}^i = \frac{w}{K}(\pi^i - k^i) + \frac{\tilde{p}C}{K}(k^i - c^i).$$

Considering the steady state, we note that $\tilde{p}C/K = r + w/K$, where $r = \rho$, and $w/K = F(.)/K - F_K(.) = F_K(.)((1/\eta) - 1) = (\delta + \rho)(1 - \eta)/\eta$. Considering ((31)), $0 = w/K(\pi^i - k^i) + w/K(k^i - c^i) + r(k^i - c^i) = w/K(\pi^i - c^i) + r(k^i - c^i) = (\delta + \rho)(1 - \eta)(\pi^i - c^i) + \eta\rho(k^i - c^i)$. Rearranging terms yields (35). ■

8.4 Proof of Proposition 2

Considering that $E = \pi_1 + \pi_2 = 1$ and normalizing aggregate labor to one, we can write the production function as $F(K, 1)$ and production per effective worker as $f(K)$. The steady state for average variables is obtained when $\dot{K} = 0$, $\dot{C} = 0$, and $\dot{W} = 0$. Since in equilibrium, $r = f'(K) - \delta$, then when $\dot{C} = 0$, $f'(K) - \delta = \rho$, or equivalently:

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

With a Cobb-Douglas production function, $rK + \omega = f(K) - \delta K$. Thus, $\dot{K} = 0$, is equivalent to:

$$\tilde{p}C = f(K) - \delta K, \tag{47}$$

and with two food types:

$$\tilde{p}_L C_L + \tilde{p}_H C_H = f(K) - \delta K. \tag{48}$$

We re-express static optimality condition (16) as $C_H^i = \frac{p_L}{p_H}\frac{1-\alpha}{\alpha}C_L^i - \frac{p_L}{p_H}\frac{1-\alpha}{\alpha}\varepsilon^i(K)\bar{C}_L$. For the average consumer, this condition simply becomes:

$$C_H = \frac{p_L}{p_H}\frac{1-\alpha}{\alpha}(1 - \varepsilon(K))C_L. \tag{49}$$

Substituting (49) into (48), we can express steady state low-calorie food consumption as:

$$C_L = \frac{\alpha}{\tilde{p}_L[1 - \varepsilon(K)(1-\alpha)]}(f(K) - \delta K). \tag{50}$$

Since the steady state stock of capital is exogenously set, it is possible to study the effect of an increase in the average steady state stock of capital on steady state average body weight. Thus:

$$\frac{\partial C_L}{\partial K} = \frac{\alpha\left(f'\left(K\right)-\delta\right)\tilde{p}_L\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]+\tilde{p}_L\varepsilon'\left(K\right)\left(1-\alpha\right)\alpha\left(f\left(K\right)-\delta K\right)}{\left\{\tilde{p}_L\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]\right\}^2},$$

$$\frac{\partial C_L}{\partial K} = \frac{\alpha\left(f\left(K\right)-\delta K\right)}{\tilde{p}_L\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\left\{\frac{\left(f'\left(K\right)-\delta\right)}{\left(f\left(K\right)-\delta K\right)}+\frac{\varepsilon'\left(K\right)\left(1-\alpha\right)}{\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\right\}, \tag{51}$$

where $1-\varepsilon\left(K\right)\left(1-\alpha\right)>0$.

As a result, since $\frac{f'(K)-\delta}{f(K)-\delta K}+\frac{\varepsilon'(K)(1-\alpha)}{1-\varepsilon(K)(1-\alpha)}>0$, $\frac{\partial C_L}{\partial K}>0$. Thus the increase in the stock of capital yields an income effect described by the additional return $\frac{f'(K)-\delta}{f(K)-\delta K}$. It also yields a dynamic positionality effect $\frac{\varepsilon'(K)(1-\alpha)}{1-\varepsilon(K)(1-\alpha)}$. Both effects result in an increase in low-calorie food consumption.

High-calorie food consumption by the average consumer is given by (48), re-written as:

$$C_H = -\frac{\tilde{p}_L}{\tilde{p}_H}C_L+\frac{f\left(K\right)-\delta K}{\tilde{p}_H}. \tag{52}$$

Thus:

$$\frac{\partial C_H}{\partial K} = -\frac{\tilde{p}_L}{\tilde{p}_H}\frac{\partial C_L}{\partial K}+\frac{f'\left(K\right)-\delta}{\tilde{p}_H}.$$

Recall that steady state body weight for the average consumer is given by:

$$W = \frac{\gamma_H}{\gamma}C_H+\frac{\gamma_L}{\gamma}C_L. \tag{53}$$

Thus:

$$\frac{\partial W}{\partial K} = \frac{\gamma_H}{\gamma}\left[\left(\frac{\gamma_L}{\gamma_H}-\frac{\tilde{p}_L}{\tilde{p}_H}\right)\frac{\partial C_L}{\partial K}+\frac{f'\left(K\right)-\delta}{\tilde{p}_H}\right]. \tag{54}$$

As a result, $\frac{\partial W}{\partial K}>0$ if $\frac{\gamma_H}{\tilde{p}_H}\left(f'\left(K\right)-\delta\right)+\gamma_L\frac{\partial C_L}{\partial K}>\gamma_H\frac{\tilde{p}_L}{\tilde{p}_H}\frac{\partial C_L}{\partial K}$, and negative otherwise. Substituting (51) into this inequality and reorganizing yields:

$$\gamma_L\frac{\left(f'\left(K\right)-\delta\right)}{\left(f\left(K\right)-\delta K\right)}+\gamma_H\frac{\tilde{p}_L}{\tilde{p}_H}\frac{\left(1-\alpha\right)\left(1-\varepsilon\left(K\right)\right)}{\alpha}\frac{\left(f'\left(K\right)-\delta\right)}{\left(f\left(K\right)-\delta K\right)}>\gamma_H\frac{\tilde{p}_L}{\tilde{p}_H}\left(\frac{\varepsilon'\left(K\right)\left(1-\alpha\right)}{\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\right)-\gamma_L\frac{\varepsilon'\left(K\right)\left(1-\alpha\right)}{\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}, \tag{55}$$

$$\frac{\left(f'\left(K\right)-\delta\right)}{\left(f\left(K\right)-\delta K\right)}\left[\gamma_L+\gamma_H\frac{\tilde{p}_L}{\tilde{p}_H}\frac{\left(1-\alpha\right)\left(1-\varepsilon\left(K\right)\right)}{\alpha}\right]>\left(\frac{\varepsilon'\left(K\right)\left(1-\alpha\right)}{\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\right)\left[\gamma_H\frac{\tilde{p}_L}{\tilde{p}_H}-\gamma_L\right]. \tag{56}$$

The LHS of the inequality denotes that the increase in the stock of capital results in a positive income effect. As a consequence, individuals increase energy intake from low-calorie food by $\gamma_L\frac{\left(f'(K)-\delta\right)}{\left(f(K)-\delta K\right)}$ and energy intake from high-calorie food by $\gamma_H\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\alpha)(1-\varepsilon(K))}{\alpha}\frac{\left(f'(K)-\delta\right)}{\left(f(K)-\delta K\right)}$. The RHS of the inequality denotes the dynamic positionality effect, which makes individuals trade high-calorie food for low-calorie food. The dynamic positionality effect results in a decrease in energy intake from high-calorie food equal to $\gamma_H \frac{\tilde{p}_L}{\tilde{p}_H}\left(\frac{\varepsilon'(K)(1-\alpha)}{[1-\varepsilon(K)(1-\alpha)]}\right)$ and an increase in energy intake from high-calorie food equal to $\gamma_L \frac{\varepsilon'(K)(1-\alpha)}{[1-\varepsilon(K)(1-\alpha)]}$. In order to gain weight, the overall additional calorie intake (LHS of the inequality) needs to exceed the net calorie decrease (RHS of the inequality). Therefore body weight increases if the income effect is larger than the dynamic positionality effect. ■

8.5 Proof of Corollary 1

With an exogenous rather than endogenous DOP, condition (55) would become:

$$\left[\gamma_L + \gamma_H \frac{\tilde{p}_L}{\tilde{p}_H} \frac{(1-\alpha)(1-\varepsilon)}{\alpha}\right] \frac{(f'(K)-\delta)}{(f(K)-\delta K)} > 0.$$

In that case, capital accumulation would solely yield a positive income effect and always result in an increase in the consumption of both high and low-calorie food. ■

8.6 Proof of Corollary 2

We compare inequality (55) for a poor and a rich country that differ according to their respective average stock of capital K^1 and K^2 ($K^1 < K^2$). Inequality (55) can simply be re-written as:

$$\frac{(f'(K)-\delta)}{(f(K)-\delta K)} > \frac{\gamma_H \frac{\tilde{p}_L}{\tilde{p}_H} - \gamma_L}{\gamma_L + \gamma_H \frac{\tilde{p}_L}{\tilde{p}_H} \frac{(1-\alpha)(1-\varepsilon(K))}{\alpha}} \frac{\varepsilon'(K)(1-\alpha)}{[1-\varepsilon(K)(1-\alpha)]}. \tag{57}$$

The LHS describes the income effect and reflects the change in income when capital increases. The RHS describes the dynamic positionality effect and reflects the change in the DOP when capital increases. If the production function is more concave than the DOP function:

$$f''(K) < \varepsilon''(K)$$

Then, for a low stock of capital K^1, inequality (57) is more likely to be verified. In that case, the income effect is more likely to be larger than the dynamic positionality effect, which yields an increase in body weight. For a stock of capital K^2 above a certain threshold of development, inequality (57) is unlikely to be verified, In that case, the income effect is likely to be smaller than the dynamic positionality effect, which yields a decrease in body weight. ■

8.7 Proof of Proposition 3

Relative individual steady state body weight is the ratio of individual steady state body weight $W^i = \frac{\gamma_H}{\gamma} C^i_H + \frac{\gamma_L}{\gamma} C^i_L$, and average steady state body weight (53):

$$w^i = \frac{\frac{\gamma_H}{\gamma} C^i_H + \frac{\gamma_L}{\gamma} C^i_L}{\frac{\gamma_H}{\gamma} C_H + \frac{\gamma_L}{\gamma} C_L} = \frac{\frac{\gamma_H}{\gamma} C_H c^i_H + \frac{\gamma_L}{\gamma} C_L c^i_L}{\frac{\gamma_H}{\gamma} C_H + \frac{\gamma_L}{\gamma} C_L}. \tag{58}$$

Substituting (50) and (52) into (58), we obtain:

$$w^i = \frac{\frac{\gamma_H}{\gamma} \frac{\tilde{p}_L}{\tilde{p}_H} \frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} c^i_H + \frac{\gamma_L}{\gamma} c^i_L}{\frac{\gamma_H}{\gamma} \frac{\tilde{p}_L}{\tilde{p}_H} \frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}}. \tag{59}$$

Thus, to calculate relative body weight, we need the expressions for c^i_H and c^i_L. They are obtained as follows. We describe the evolution of relative capital using $\frac{\dot{k}^i}{k^i} = \frac{\dot{K}^i}{K^i} - \frac{\dot{K}}{K}$, which yields $\frac{\dot{k}^i}{k^i} = \frac{\omega}{K}\left(\frac{\pi^i}{k^i} - 1\right) - \frac{\tilde{p}C}{K}\left(\frac{c^i}{k^i} - 1\right)$. In the steady state, $\frac{\dot{k}^i}{k^i} = 0$. As a result:

$$\tilde{p}C = \omega \frac{\pi^i - k^i}{c^i - k^i}.$$

Using (47), we obtain:

$$c^i = \omega \frac{\pi^i - k^i}{f(K) - dK} + k^i. \tag{60}$$

Accounting for the two food types, we reexpress the left-hand side of this equation as $c^i = \frac{\tilde{p}_L c^i_L C_L + \tilde{p}_H c^i_H C_H}{\tilde{p}_L C_L + \tilde{p}_H C_H}$. Using static optimality condition (16) expressed as (49) for average consumption, and $C^i_H = \frac{p_L}{p_H} \frac{1-\alpha}{\alpha} C^i_L - \frac{p_L}{p_H} \frac{1-\alpha}{\alpha} \varepsilon^i(K) \bar{C}_L$, with $C_L = \bar{C}_L$ for individual consumption, we re-express c^i as a function of c^i_L:

$$c^i = \frac{\tilde{p}_L C^i_L + \tilde{p}_H \left[\frac{p_L}{p_H} \frac{1-\alpha}{\alpha} C^i_L - \frac{p_L}{p_H} \frac{1-\alpha}{\alpha} \varepsilon^i(K) \bar{C}_L\right]}{\tilde{p}_L C_L + \tilde{p}_H \frac{p_L}{p_H} \frac{1-\alpha}{\alpha} (1 - \varepsilon(K)) C_L} = \frac{\left(1 + \frac{1-\alpha}{\alpha}\right) c^i_L - \frac{1-\alpha}{\alpha} \varepsilon^i(K)}{1 + \frac{1-\alpha}{\alpha} (1 - \varepsilon(K))}. \tag{61}$$

Substituting (60) in (61), we obtain c^i_L:

$$c^i_L = \frac{\left[\omega \frac{\pi^i - k^i}{f(K) - dK} + k^i\right] \left[1 + \frac{1-\alpha}{\alpha} (1 - \varepsilon(K))\right] + \frac{1-\alpha}{\alpha} \varepsilon^i(K)}{1 + \frac{1-\alpha}{\alpha}},$$

$$c^i_L = \alpha \left\{ \left[\omega \frac{\pi^i - k^i}{f(K) - \delta K} + k^i\right] \left[1 + \frac{1-\alpha}{\alpha} (1 - \varepsilon(K))\right] + \frac{1-\alpha}{\alpha} \varepsilon^i(K) \right\},$$

$$c^i_L = \left[\omega \frac{\pi^i - k^i}{f(K) - \delta K} + k^i\right] \left[\alpha + (1-\alpha)(1 - \varepsilon(K))\right] + (1-\alpha) \varepsilon^i(K). \tag{62}$$

We now express c_H^i as a function of c_L^i. Using (16), (52), and (50) we obtain:

$$c_H^i = \frac{c_L^i - \varepsilon^i(K)}{1-\varepsilon(K)}. \tag{63}$$

Substituting (62) and (63) into (59), we obtain:

$$w^i = \frac{\left[\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}\right]\left[\frac{\omega\pi^i}{f(K)-dK} + k^i\left(1-\frac{\omega}{f(K)-\delta K}\right)\right]\left[\alpha + (1-\alpha)(1-\varepsilon(K))\right] - (1-\alpha)\left(\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H} - \frac{\gamma_L}{\gamma}\right)\varepsilon^i(K)}{\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}}. \tag{64}$$

As a result, the relative body weight of an individual depends upon her relative productivity, relative wealth, relative DOP, the relative energy density of high-calorie food compared to the relative price of high-calorie food, and average positionality. Since we have considered that individual consumption and saving decisions have no effect on the average stock of capital, an increase in the individual stock of capital is equivalent to the effect of an increase in the relative stock of capital. Thus:

$$\frac{\partial w^i}{\partial k^i} = \frac{\left[\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}\right]\left(\frac{rK}{f(K)-\delta K}\right)\left[\alpha + (1-\alpha)(1-\varepsilon(K))\right]}{\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}}. \tag{65}$$

Considering that $1 - \frac{\omega}{f(K)-\delta K} > 0$, $\frac{\partial w^i}{\partial k^i} > 0$. Furthermore:

$$\frac{\partial w^i}{\partial \pi^i} = \frac{\left[\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}\right]\frac{\omega}{f(K)-\delta K}\left[\alpha + (1-\alpha)(1-\varepsilon(K))\right]}{\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}}. \tag{66}$$

Considering restrictions on parameters, $\frac{\partial w^i}{\partial \pi^i} > 0$. Furthermore, given K:

$$\frac{\partial w^i}{\partial \varepsilon^i(K)} = -\frac{(1-\alpha)\left(\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H} - \frac{\gamma_L}{\gamma}\right)\frac{\partial \varepsilon^i(K)}{\partial \varepsilon^i}}{\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}}. \tag{67}$$

Therefore, $\frac{\partial w^i}{\partial \varepsilon^i(K)} < 0$ if $\frac{\gamma_H}{\gamma_L} > \frac{\tilde{p}_H}{\tilde{p}_L}$. It is important to notice that we are considering an increase in the DOP, which is unrelated to the stock of capital. Therefore, we are considering a change in the static DOP. In the same way, $\frac{\partial w^i}{\partial \epsilon^i(K)} < 0 \; if \frac{\gamma_H}{\gamma_L} > \frac{\tilde{p}_H}{\tilde{p}_L}$. ■

8.8 Proof of Corollary 3

From (64), and (65), if $k^i > k^j$, $w^i > w^j$. From (64), and (66), if $\pi^i > \pi^j$, $w^i > w^j$. From (64), and (67) if $\varepsilon^i > \varepsilon^j$, $w^i < w^j$. Therefore, the larger the differences in relative wealth or productivity, the larger the differences in relative body weight. The larger the differences in relative positionality, the smaller the differences in relative body weight. ■

8.9 Proof of Corollary 4

$$\frac{\partial w^i}{\partial K} = \frac{\partial w^i}{\partial k^i}\frac{\partial k^i}{\partial K} \tag{68}$$

Since $k^i = \frac{K^i}{K}$, $\frac{\partial k^i}{\partial K} < 0$. Since $\frac{\partial w^i}{\partial k^i} > 0$, $\frac{\partial w^i}{\partial K} < 0$. Therefore, relative body weight decreases with average wealth. ■

8.10 Proof of Proposition 4

We show the effect of a change in the price of low-calorie food on equilibrium body weight. Recall that steady state average low-calorie food consumption is given by:

$$C_L = \frac{\alpha}{\tilde{p}_L\left[1-\varepsilon(K)(1-\alpha)\right]}\left(f(K)-\delta K\right). \tag{69}$$

As a result, with K being exogenous in the steady state:

$$\frac{\partial C_L}{\partial \tilde{p}_L} = -\frac{\alpha}{\tilde{p}_L^2\left[1-\varepsilon(K)(1-\alpha)\right]}\left(f(K)-\delta K\right). \tag{70}$$

Therefore:

$$\frac{\partial C_L}{\partial \tilde{p}_L} < 0.$$

Recall that:

$$C_H = \frac{p_L}{p_H}\frac{1-\alpha}{\alpha}\left(1-\varepsilon(K)\right)C_L = \frac{\tilde{p}_L}{\tilde{p}_H}\frac{1-\alpha}{\alpha}\left(1-\varepsilon(K)\right)C_L. \tag{71}$$

As a result:

$$\frac{\partial C_H}{\partial \tilde{p}_L} = \frac{1}{\tilde{p}_H}\frac{1-\alpha}{\alpha}\left(1-\varepsilon(K)\right)C_L + \frac{\tilde{p}_L}{\tilde{p}_H}\frac{1-\alpha}{\alpha}\left(1-\varepsilon(K)\right)\frac{\partial C_L}{\partial \tilde{p}_L},$$

equivalently:

$$\frac{\partial C_H}{\partial \tilde{p}_L} = \frac{1}{\tilde{p}_H}\frac{1-\alpha}{\alpha}\left(1-\varepsilon(K)\right)\frac{\alpha}{\tilde{p}_L\left[1-\varepsilon(K)(1-\alpha)\right]}\left(f(K)-\delta K\right),$$

$$-\frac{\tilde{p}_L}{\tilde{p}_H}\frac{1-\alpha}{\alpha}\left(1-\varepsilon(K)\right)\frac{\alpha}{\tilde{p}_L^2\left[1-\varepsilon(K)(1-\alpha)\right]}\left(f(K)-\delta K\right),$$

which simplifies to yield:

$$\frac{\partial C_H}{\partial \tilde{p}_L} = 0.$$

In the steady state, the cross price elasticity of high-calorie food consumption equals zero. Thus:

$$\frac{\partial W}{\partial \tilde{p}_L} = \frac{\gamma_H}{\gamma}\frac{\partial C_H}{\partial \tilde{p}_L} + \frac{\gamma_L}{\gamma}\frac{\partial C_L}{\partial \tilde{p}_L} \tag{72}$$

is equivalent to:

$$\frac{\partial W}{\partial \tilde{p}_L} = \frac{\gamma_L}{\gamma}\frac{\partial C_L}{\partial \tilde{p}_L}. \tag{73}$$

Therefore:

$$\frac{\partial W}{\partial \tilde{p}_L} < 0. \tag{74}$$

We now show the effect of a change in the price of high-calorie food on equilibrium body weight. Recall that:

$$C_L = \frac{\alpha}{\tilde{p}_L\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\left(f\left(K\right)-\delta K\right). \tag{75}$$

Using (69) and (71), we deduce that:

$$C_H = \frac{1}{\tilde{p}_H}\frac{\left(1-\alpha\right)\left(1-\varepsilon\left(K\right)\right)}{\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\left(f\left(K\right)-\delta K\right). \tag{76}$$

As a consequence:

$$\frac{\partial C_H}{\partial \tilde{p}_H} = -\frac{1}{\tilde{p}_H^2}\frac{\left(1-\alpha\right)\left(1-\varepsilon\left(K\right)\right)}{\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\left(f\left(K\right)-\delta K\right), \tag{77}$$

$$\frac{\partial C_H}{\partial \tilde{p}_H} < 0,$$

and:

$$\frac{\partial C_L}{\partial \tilde{p}_H} = 0.$$

In the steady state, the cross price elasticity of low-calorie food consumption equals zero. As a result:

$$\frac{\partial W}{\partial \tilde{p}_H} = \frac{\gamma_H}{\gamma}\frac{\partial C_H}{\partial \tilde{p}_H} + \frac{\gamma_L}{\gamma}\frac{\partial C_L}{\partial \tilde{p}_H} = \frac{\gamma_H}{\gamma}\frac{\partial C_H}{\partial \tilde{p}_H}. \tag{78}$$

Therefore:

$$\frac{\partial W}{\partial \tilde{p}_H} < 0. \tag{79}$$

■

8.11 Proof of Corollary 5

Recall that:

$$\frac{\partial C_L}{\partial \tilde{p}_L} = -\frac{\alpha\left(f\left(K\right)-\delta K\right)}{\tilde{p}_L^2\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}. \tag{80}$$

When the stock of capital is high, the numerator (depending on income) is large and the denominator (depending on the DOP) is small. As a result, $\frac{\partial C_L}{\partial \tilde{p}_L}$ is large and more negative. Thus, a subsidy to low-calorie food is likely to yield a larger increase in the consumption of low-calorie food and increase body weight in a rich country than in a poor country.

Recall that:

$$\frac{\partial C_H}{\partial \tilde{p}_H} = -\frac{1}{\tilde{p}_H^2}\frac{\left(1-\alpha\right)\varepsilon\left(K\right)}{\left[1-\left(1-\alpha\right)\varepsilon\left(K\right)\right]}\left(f\left(K\right)-\delta K\right). \tag{81}$$

When the stock of capital is high, the ratio $\frac{\left[(1-\alpha)\varepsilon(K)\right]}{\left[1-(1-\alpha)\varepsilon(K)\right]}$ is large, and income $\left(f\left(K\right)-dK\right)$ is large. Therefore, when the stock of capital is high, a tax on high-calorie food yields a stronger decrease in high-calorie food consumption and body weight than when the stock of capital is low. ■

8.12 Proof of Proposition 5

Using (70) and (77), the effect on body weight of a one percent increase in $\tilde{p}_H$ combined with a one percent decrease in $\tilde{p}_L$ is given by:

$$\frac{\partial W}{\partial \tilde{p}_H}\frac{\tilde{p}_H}{W} - \frac{\partial W}{\partial \tilde{p}_L}\frac{\tilde{p}_L}{W} = \frac{\gamma_H}{\gamma}\frac{\partial C_H}{\partial \tilde{p}_H}\frac{\tilde{p}_H}{W} - \frac{\gamma_L}{\gamma}\frac{\partial C_L}{\partial \tilde{p}_L}\frac{\tilde{p}_L}{W},$$

$$\frac{\gamma_H}{\gamma}\frac{\partial C_H}{\partial \tilde{p}_H}\frac{\tilde{p}_H}{W} - \frac{\gamma_L}{\gamma}\frac{\partial C_L}{\partial \tilde{p}_L}\frac{\tilde{p}_L}{W} = \frac{\gamma_H}{\gamma}\left(-\frac{1}{\tilde{p}_H^2}\frac{\left(1-\alpha\right)\left(1-\varepsilon\right)}{\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\left(F\left(K\right)-\delta K\right)\right)\frac{\tilde{p}_H}{W}$$

$$+\frac{\gamma_L}{\gamma}\frac{\alpha}{\tilde{p}_L^2\left[1-\varepsilon\left(K\right)\left(1-\alpha\right)\right]}\left(F\left(K\right)-\delta K\right)\frac{\tilde{p}_L}{W}.$$

Using the steady state expression for body weight (53), we obtain:

$$\frac{\partial W/W}{\partial \tilde{p}_H/\tilde{p}_H} - \frac{\partial W/W}{\partial \tilde{p}_L/\tilde{p}_L} = \frac{\gamma_L\frac{\alpha}{\tilde{p}_L} - \gamma_H\frac{(1-\alpha)(1-\varepsilon(K))}{\tilde{p}_H}}{\gamma_L\frac{\alpha}{\tilde{p}_L} + \gamma_H\frac{1}{\tilde{p}_H}\left(1-\alpha\right)\left(1-\varepsilon\left(K\right)\right)}.$$

As a result, body weight decreases if $\frac{\gamma_L}{\gamma_H}\frac{\alpha}{(1-\alpha)(1-\varepsilon(K))} < \frac{\tilde{p}_L}{\tilde{p}_H}$, and increases otherwise. ■

8.13 Proof of Corollary 6

When the stock of capital is relatively low (high), the LHS of the equation is relatively low (high) and the above inequality is more (less) likely to hold. ■

8.14 Proof of Proposition 6

Recall that:

$$w^i = \frac{\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha}c_H^i + \frac{\gamma_L}{\gamma}c_L^i}{\frac{\gamma_H}{\gamma}\frac{\tilde{p}_L}{\tilde{p}_H}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}}, \tag{82}$$

$$\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)} = \frac{\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha}\frac{\gamma_L}{\gamma}}{\left[\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}\frac{\tilde{p}_H}{\tilde{p}_L}\right]^2}\left(c_H^i - c_L^i\right), \tag{83}$$

where c_H^i and c_L^i, defined in equations (62) and (63), and do not depend on relative prices. The sign of $\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}$ depends upon the sign of $c_H^i - c_L^i$.

$$c_H^i - c_L^i = \frac{c_L^i - \varepsilon^i(K)}{1-\varepsilon(K)} - c_L^i = -\frac{\varepsilon^i(K) - \varepsilon(K)c_L^i}{1-\varepsilon(K)}; \tag{84}$$

$$c_H^i - c_L^i = -\frac{\varepsilon^i(K) - \varepsilon(K)\left\{\left[\omega\frac{\pi^i - k^i}{f(K)-\delta K} + k^i\right][\alpha + (1-\alpha)(1-\varepsilon(K))] + (1-\alpha)\varepsilon^i(K)\right\}}{1-\varepsilon(K)}; \tag{85}$$

$$c_H^i - c_L^i = \frac{\left\{\varepsilon(K)\left[\frac{\omega\pi^i}{f(K)-\delta K} + \frac{rKk^i}{f(K)-\delta K}\right] - \varepsilon^i(K)\right\}[1-\varepsilon(K)(1-\alpha)]}{1-\varepsilon(K)}. \tag{86}$$

As a result, $\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)} < 0$ if $c_H^i < c_L^i$, or equivalently:

$$\epsilon^i(K) > \left[\frac{\omega\pi^i}{f(K)-\delta K} + \frac{rKk^i}{f(K)-\delta K}\right]. \tag{87}$$

The effect of a relative increase in the price of high-calorie food depends upon relative productivity and wealth compared to relative and average positionality. If relative productivity and wealth are larger (smaller) than relative positionality, body weight increases (decreases) when the relative cost of high-calorie food increases, because individuals consume relatively more (less) high-calorie food compared to low-calorie food.

Inequality (87) can further be simplified considering that we have a Cobb-Douglas production function, such that $rK + \omega = f(K) - \delta$, and setting $\delta = 0$, the RHS of the inequality represents the individual's share of total income y^i, or ranking in the (total) income distribution:

$$\epsilon^i(K) > \left[\frac{\omega\pi^i + rKk^i}{f(K)}\right],$$

$$\epsilon^i(K) > y^i.$$

■

8.15 Proof of Corollary 7

We re-express (83) as:

$$\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)} = \frac{\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha}\frac{\gamma_L}{\gamma}}{\left[\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}\frac{\tilde{p}_H}{\tilde{p}_L}\right]^2}\frac{\left\{\varepsilon(K)\left[\frac{\omega\pi^i}{f(K)-\delta K} + \frac{rKk^i}{f(K)-\delta K}\right] - \varepsilon^i(K)\right\}\left[1-\varepsilon(K)(1-\alpha)\right]}{1-\varepsilon(K)}. \tag{88}$$

Recall that when the individual stock of capital increases, it has no effect on the average stock of capital. Therefore, we obtain:

$$\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}/\partial k^i = \frac{\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha}\frac{\gamma_L}{\gamma}}{\left[\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}\frac{\tilde{p}_H}{\tilde{p}_L}\right]^2}\frac{\left\{\varepsilon(K)\left[\frac{rK}{f(K)-\delta K}\right] - \varepsilon^i(K)\right\}\left[1-\varepsilon(K)(1-\alpha)\right]}{1-\varepsilon(K)}. \tag{89}$$

As a result, $\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}/\partial k^i < 0$ if $\epsilon^i(K) > \frac{rK}{f(K)-\delta K}$. The inequality can further be simplified considering that we have a Cobb-Douglas production function, such that $f(K) = K^\alpha$, and setting $\delta = 0$, we obtain $\epsilon^i(K) > \alpha$.

The increase in the relative cost of high-calorie food is more effective at reducing relative body weight for relatively rich individuals if relative positionality is larger than average capital income. Furthermore:

$$\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}/\partial \pi^i = \frac{\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha}\frac{\gamma_L}{\gamma}}{\left[\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha} + \frac{\gamma_L}{\gamma}\frac{\tilde{p}_H}{\tilde{p}_L}\right]^2}\frac{\left\{\varepsilon(K)\left[\frac{\omega}{f(K)-\delta K}\right] - \varepsilon^i(K)\right\}\left[1-\varepsilon(K)(1-\alpha)\right]}{1-\varepsilon(K)}.$$

As a result, $\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}/\partial \pi^i < 0$ if $\epsilon^i(K) > \frac{\omega}{f(K)-\delta K}$. The increase in the relative cost of high-calorie food is more effective at reducing relative body weight for more productive individuals if relative positionality is larger than average labor income. The inequality can further be simplified considering that we have a Cobb-Douglas production function, such that $f(K) = K^\alpha$, and setting $\delta = 0$, we obtain $\epsilon^i(K) > 1-\alpha$.

Furthermore:

$$\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}/\epsilon^i = -\frac{\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha}\frac{\gamma_L}{\gamma}}{\left[\frac{\gamma_H}{\gamma}\frac{(1-\varepsilon(K))(1-\alpha)}{\alpha}+\frac{\gamma_L}{\gamma}\frac{\tilde{p}_H}{\tilde{p}_L}\right]^2}\frac{\varepsilon(K)\left[1-\varepsilon(K)(1-\alpha)\right]}{1-\varepsilon(K)}. \tag{90}$$

As a result, $\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}/\partial\epsilon^i < 0$. The increase in the relative cost of high-calorie food is more effective at reducing relative body weight for individuals with a higher static DOP. ■

8.16 Proof of Corollary 8

$$\frac{\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}}{\partial K} = \frac{\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}}{\partial k^i}\frac{\partial k^i}{\partial K}$$

Since $\frac{\partial k^i}{\partial K} < 0$, $\frac{\partial w^i}{\partial\left(\frac{\tilde{p}_H}{\tilde{p}_L}\right)}/\partial K > 0$ if $\epsilon^i(K) > \frac{rK}{f(K)-\delta K}$. The inequality can further be simplified considering that we have a Cobb-Douglas production function, such that $f(K) = K^\alpha$, and setting $\delta = 0$, we obtain $\epsilon^i(K) > \alpha$. The increase in the relative cost of high-calorie food is less effective at reducing relative body weight in rich countries compared to poor countries if relative positionality is larger than the contribution of capital intensity to production. ■

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