Evolutionary Dynamics of the Obesity-Socioeconomic Status Paradox: A Veblenian Hypothesis*

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December 7, 2016

Abstract

In the traditional society, obesity is associated with high socioeconomic status (SES), while in the modern society, especially among women, it is associated with low SES, accompanying with the weight discrimination. We find these patterns consistent with the evolutionary dynamics based on a Veblenian hypothesis, in which body weight is used as the means of social class division. Given the changing incomes and relative costs of calories intake and expenditure, high-SES individuals choose a body weight to distinct themselves from the low-SES, and low-SES individuals try to imitate the high-SES while competing with each other. Our game-theoretical analysis predicts patterns supported by statistical and literature evidence of obesity-SES associations and social perceptions toward obesity. This is the first paper analyzing the evolution of obesity-SES paradox and the endogenous formation of the inter-class social norm within an integrated framework.

Keywords: obesity, health inequality, weight discrimination, evolutionary game theory

JEL Classification: I14, I15, B52, C73

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*We thanks the great helps and insightful comments by Nancy Folbre, Peter Skott, Hongli Wei, Yoshihara Naoki, participants of the Analytical Political Economy seminar 2016 Spring and the New School-UMASS graduate student workshop 2016. All errors are our own.

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1 Introduction

One of the most interesting and robust findings in the obesity literature is the obesity-socioeconomic status (SES) paradox, or more precisely, the reversal in the obesity-SES association. Several empirical studies find that obesity is a characteristic associated with the upper-SES class in many traditional societies. But as the economy develops, this association reverses. In relatively developed countries, obesity is a characteristic strongly associated with lower-SES classes (Sobal & Stunkard, 1989; Sobal, 1991; Monteiro, et al., 2004; Pampel, et al., 2012).

Accompanying with this reversal, the reversal of the social perception of ideal body weight is equally considerable. Anthropological studies document that traditional societies in fact celebrate obesity, as shown in the famous "Venus of Willendorf" in Figure 1 (Cassidy, 1991). In contrast, the not-so-subtle message from the pop culture, for instance, *The Biggest Loser (2013)*, indicates that obesity today are viewed pretty negatively, often thought to be gluttonous, lazy, lacking self-control and self-reliance, and even mentally or physically ill (Oliver, 2006; Puhl, 2011).[1] Reflecting this negative perception, penalties against obese people are repeatedly reported in various areas, such as marriages, labor markets, schools, and health services. Importantly, these negative impacts have been found to be most pronounced for women (Averett, 2011; Puhl, 2011; Chen, 2012; Caliendo & Gehrsitz, 2016).

This paper proposes a Veblenian hypothesis to analyzes the twin reversals in an integrated, dynamic framework. Based on Veblen's theory of social division by consumption patterns (Veblen, 1899), we argue that the choices of body weight, through various ways of calories intakes and expenditures, are fundamentally class practices. The dominant perception reflects the behaviors of the high-SES class, and the body weight is used as the means of social division. The high-SES class chooses a body weight that can distinct themselves from the low-SES class. The low-SES class tries to imitate the choice of high-SES class, while competes with each other for limited opportunities of upward mobility.

In the traditional society, the big weight is used by the high-SES class as a sign of abundance and social status. The low-SES class is unable to gain weight due to the constraints of high food prices relative to income, and the calories expenditures required

[1] In 2013, The American Medical Association officially recognized obesity as a disease in itself (Pollack, 2013).

Venus of Willendorf
(28,000 and 25,000 BCE.)

The Biggest Loser (2004-)

Figure 1: The contrasted views of the obese (woman) in traditional and modern societies. *Left:* The "Venus of Willendorf", also known as the *Woman of Willendorf*, a figurine now is in the Naturhistorisches Museum in Vienna, Austria. By estimation, it was created between 28,000 B.C.E. - 25,000 B.C.E., and discovered in 1908 near Willendorf, Austria. *Right:* An image clipped from a TV program, *The Biggest Loser (2013)*.

by labor. In the modern society, as the prices of low-quality foods relative to incomes decline dramatically, and work and life styles change, it becomes more expensive to keep slim than gaining weights, both in terms of the relative money and time costs. In this case, the low-SES class faces more difficulties to lose weight than to gain weight. The high-SES class switches its strategy toward slimness to maintain the social division, and the weight discrimination against obesity people emerges accordingly. In this paper, we present an evolutionary-game-theory model to analyze the process.

Our model extends Veblen's original analysis of conspicuous consumption along few reconsiderations. First, Veblen's book appeared at the time when the transition from traditional to modern society just began. As he argued that the reputability of excessive indulgence for wealthy men was a legacy from the "early stage of culture [in which] the symptoms of expensive vice are conventionally accepted as marks of a superior status" (Veblen, 1899), the standing point of his argument is already part of the new social perception that opposes the honorific indulgence of food consumption, which then become the norm of our time and should be analyzed as well. Second, Veblen keenly points out different social perceptions upon men and women, as he suggested that women are

not allowed to consume beyond their subsistence unless the consumption can comfort or bring good repute for her master (Veblen, 1899). However, the constraint of food consumption of women and the preference for a slim body is not that common before Veblen's days. What Veblen suggested, as we show in the section 2.2, likely reflects the new norm against fat body that emerges firstly in the U.S. at the end of the 19th century (Seid, 1989). It is applied more strongly upon women since, as Veblen suggests, women are treated as chattels of men and got judged more by their appearances. Based on these reconsiderations, we therefore incorporate the lessons from eras before and after Veblen, and extend Veblen's thoughts into a dynamic framework which is able to account for the reversal in norms and forms of consumption over longer historical length, while still bases on the same logic of class distinction.

It is important to note that the costs of gaining and losing weight in our model include not only monetary costs, but also cognitive costs in processing information suggested by the behavioral economics (Smith, 2004; Mani, et al., 2013; Smith & Tasnádi, 2014).[2] It will become clear when we introduce our model that our settings do take into account of this element by incorporating cognitive costs into the relative costs of calories intake and expenditure.

In addition to theoretical modeling, we further present empirical evidence for the obesity-SES association by statistically analyzing a large cross-country sample covering 66 developing countries. We also present evidence of social perception of ideal body and weight discrimination from the literature.

While these two historical reversals are widely recognized in the literature, there is no systematic explanation, to the best of our knowledge, of their formations, transitions, and interactions between them. The only explanation partially touched upon this issue in the literature is suggested by Philipson & Posner (1999), Lakdawalla, Philipson & Bhattacharya (2005), and Lakdawalla & Philipson (2009). Their main focus is on the growth of obesity rate in the general population, which is explained by technological improvements such that work and lifestyles become sedentary, food prices decrease, and therefore the calories intakes tend to overpass the calories expenditures in the modern society. Against this general trend, the high-SES class starts to change its behaviors toward slimness, because it starts realizing the health risk of being overweight/obese,

[2]The behavioral economics is by no mean a unified approach, and we are not able to incorporate several other behavioral factors due to the limited scope of this paper. Please see Cutler, Glaeser, & Shapiro (2003) and Downs & Loewenstein (2011) for more discussions.

and its preference for health changes as income grows.[3] They also suggests that the low-SES class will change its preference and start to lose weight in the future as its income increases.

To our research question, however, this explanation raises more questions than answers. First, it's not very clear how high the income should be in order to turn an individual to demand health and thinness. The empirical evidence shows that the high-SES class in the traditional society didn't try to lose weight, although it had been well off for some time. And the low-SES class today seems still not (or even less) to do so, given its living standard has improved significantly. Second, a more serious problem is: this explanation is difficult to account for especially the weight difference between the female and male of the high-SES. In spite of sharing similar health preference and information among the high-SES agents, today's high-SES female is much thinner than her low-SES counterpart, while the high-SES male's weight is relatively similar to the low-SES male (Pampel, Denney, & Krueger, 2012). In their explanation, it's hard to imagine why high-SES females would gain new health knowledge before males, given the fact that females usually do not have better education opportunities than males.

In the context of economic study on obesity, this paper makes three innovations. First, compared with the mainstream explanation, we show that the obesity-SES paradox and the twin reversals can be derived from a set of institutional principles, without relying on arbitrary assumptions of preference changes. We further show that the effects of the changes in costs of calories intakes and expenditures are mediated by these institutional principles, leading to heterogeneous outcomes for different classes.

Second, previous theoretical analyses of obesity mostly build on the methodology of representative individualism. This makes them difficult to address the complex interactions and influences between different social classes regarding the choices of body weights. By analyzing the interactions between two classes which have heterogeneous behavioral rules within a model, we can explain the evolution of obesity-SES association and the endogenous class norm of social division.

Third, several studies emphasize that the crucial role played by one type of social norm, the peer effect, which may lead to higher prevalence of obesity with certain groups (Burke & Heiland, 2006; 2007). This approach is complementary with ours. We agree

[3]The strong (causal) link between overweight/obesity and various health risks is the foundation for many obesity researches. There are some controversies over the extent and causality of the link. See Neel, et al. (1998), Campos, et al. (2006), and Campos (2011) for critical perspectives.

on the importance of social norms, but emphasize a different set of norms that receive little formal analysis in the literature. We focus on the norms regarding inter-classes interactions between classes. We also demonstrate that how the intra-class competition effect, the effect comes from the competition among low-SES agents for the limited opportunity of upward mobility, can play a role in determining patterns consistent with the evidence.

To focus on the formation and co-evolution of the obesity-SES association and the social perception of body weight, we limit the scope of our analysis in several respects that have been addressed in the literature. First, we do not provide an alternative theory of the growth of obesity in the general population. In this respect, we agree with the mainstream explanation about the role played by the changing costs of calories intakes and expenditures, which are significantly influenced by technological changes. We also agree with the behavioral approach that several behavioral factors may have important impacts on the costs. Second, by focusing on the social class in general, with an emphasis on the female, we do not address the different obesity distribution between different ethical groups. Because the evidence of obesity-ethnicity association is still limited in few countries, and the pattern seems to be influenced more by the history and ethical relationships within specific societies and time periods, and interacts with SES in a complex way. Third, although we show that the patterns of obesity-SES paradox can be explained without referring to changes in the health knowledge and preference, we do not deny the influence of health knowledge and preference. What we try to do is to suggest that there are something more that cannot be well explained by the health preference, e.g., the difference between high-SES female and male.

The paper is organized as follows. In section 2, we provide empirical evidence of obesity-SES association, and of the social perception and weight discrimination as well. Section 3 layouts the behavioral and institutional settings of our model, which then is employed in section 4 to analyze the comparative statics of the evolution of obesity-SES association from traditional to modern societies.

2 Empirical motivation: the twin reversals

2.1 The association between obesity and SES

The ideal set of empirical evidence for our hypothesis is the evolution of the obesity-SES association within a specific society as the economy develops over time. However, due to the limitation of data, it's difficult to analyze directly the pattern in societies of the pre-modern era. Instead, most studies use contemporary cross-national data which cover societies of different economic development levels as a proxy.

Our statistical analyses follow the seminal work by Monteiro, et al. (2004) and make several extensions. We obtain every survey in the Demographic and Health Survey (DHS) database which contains the information needed, and restrict our analyses to non-pregnant women aged 20-49 years. The resulted sample covers 66 developing countries, 247 distinct country-years, with a total of 1,368,694 observations. The time period ranges between year 1991 to 2015.

The main variables obtained from the data sets are: body mass index (BMI), age groups (5-year intervals), and education in single years. Following the convention in the literature, we define BMI ≥ 30 as obesity, and calculate each country's quartiles of women's years of education and use the individual's relative education level as the proxy of SES.

We append the sample with the data of real GDP per capita (in constant 2010 U.S. dollars), which is collected and computed by the World Bank (WB), at the year of survey to measure the level of economic development for each country-year. We also take into account of survey sampling weights and the survey designs while implementing our statistical analyses, following the standard approach in the literature and the guidance of DHS program (Rutstein & Rojas, 2006). Based on this sample, we are able to calculate for each country-year the age-standardized prevalence rate of obesity among women of different SES groups.

To capture the pattern of the reversal over different levels of economic developments, we categorize all observations into three groups based on the WB year 2003 classification: a) low income economies ($\leq$ \$825), b) low-middle income economies (\$825 $<$ & $\leq$ \$3255), and c) high-middle income economies ($>$ \$3255). We then calculate for each income group the age-standardized prevalence rate of obesity among women of different SES groups. Finally, we compute the age-standardized prevalence ratios for each income

group by using the obesity rate in the lowest SES class (Q1) as the common reference. The result is presented in Table 1.

Table 1: Age-standardized prevalence ratio for women's obesity by quartiles (Q) of SES in low, lower-middle, and upper-middle income economies (1991-2015)

real GDP per capita (in 2010 U.S. dollars)	Number of country-year	Q1/Q1	Q2/Q1	Q3/Q1	Q4/Q1
$\leq$ \$825	109	1.0	1.93	2.29	4.26
\$825-\$3255	100	1.0	1.32	1.62	1.46
$>$ \$3255	36	1.0	1.17	1.01	0.84

Table 1 indicates that the relative obesity prevalence rate declines for the higher SES class as the economy develops. In the low income economies, the age-standardized prevalence ratio for women in the highest SES class vis-à-vis the lowest SES class (Q4/Q1) is 4.26, i.e., the highest SES women are more than 4 time likely to be obese than the lowest SES women. In contrast, the ratio declines to 0.84 in the high-middle income economies, i.e., the highest SES women is less likely to be obese than the lowest SES women. Similar patterns occur for the second and third quartiles of SES women. The results are consistent with our hypothesis.

2.2 Social perception on obesity

It's not surprising that the reversal in the obesity-SES association is closely related and interact with the social perception toward obesity. On the one hand, in the class society, the social perception of body weights generally reflects the preference and behaviors of the high-SES class. Therefore, the society celebrating obesity is more likely to be a society in which the high-SES class tends to has a bigger weight, and the society discriminating against obesity is more likely to be a society in which the high-SES class tends to weigh less. On the other hand, the current obesity-SES association results partly from the high-SES class's weight discrimination, backed up by its material powers, which not only scares its members away from being obese but also hinders the upward mobility of obese people.

In terms of the inter-temporal evidence for the ideal body weight, since fine art works were usually commissioned and owned by the high SES class in the pre-modern societies, the body images of women in fine art works are likely to reflect the high SES group's perception of the ideal women body weight. In this respect, we should not be surprised

that the development is by no means monotonically due to a variety of ideological factors. For example, the ideal body type in the Western art in the early medieval era tends to be slim and emaciated, showing the heavy influence from the Catholic church which believes the pleasure of eating is a gateway to sins (Woodhouse, 2008). This is changed later in the 17th century, as a series of artists, from Rubens (1577-1640), Rembrandt (1606-1669), to Renoir (1841-1919), start to paint the massive, fleshy body as a symbol of wealth and social status. Many figures in their paintings are definitely overweight or obese by today's standard (Eknoyan, 2006; Woodhouse, 2008; Bonafini & Pozzilli, 2011). The reversal occurred in the end of the 19th century, first in the U.S., just when the improvement of living standard made that fatness can be a 'choice' to many, for the first time in history. It is particularly interesting to note that the new ideal body image, slimness, was emerged at that time as a novel way to 'stand out' from the crowd (Woodhouse, 2008: 279-281; Seid, 1989).

In addition to the inter-temporal evidence from art works, a large body of contemporary cross-country studies find that, although not without variation across cultures, in less developed societies, plumpness, being overweight or even obese, is linked with positive traits of fertility, sexuality, and attractiveness, while in more developed societies, the ideal body weight is slimmer or underweight (Swami, 2007; Swami & Furnham, 2008; Swami, et al., 2010). For example, Swami and co-authors conduct a series of experiments in different countries. They find that individuals in less developed societies tend to evaluate overweight or obese figures positively, while individuals in more developed societies rate slender or underweight figures as being more attractive (Swami, et al., 2010).

In modern societies as the ideal body weight of high SES class changes, the pressure to keep slim leads to weight discrimination in schools, labor markets, health services, and marriage markets (Puhl & Heuer, 2009; Puhl, 2011). The discrimination is even justified and re-enforced by the false belief that such stigmatization may motivate obese people to lose weight (Puhl & Heuer, 2010). For example, by surveying the attitudes of 368 university students, Latner, et al., (2008) report that weight discrimination is socially acceptable and stronger than gender-orientation and religious biases.

Similar with other forms of discrimination, the weight discrimination strengthens the association between obesity and low SES class through various channels in the modern society (Hatzenbuehler, Phelan, & Link, 2013). Several studies shows that, the penalty based on the weight discrimination is partly the reason why obesity in developed countries

is more significant among low-SES women: it might not be that low-SES women are more likely to obese, but because over-weighted women suffer more from the income and other social resource penalty, and then are squeezed into the lower-SES class (Cawley, 2004; Han, Norton & Stearns, 2009; Caliendo & Gehrsitz, 2016).

3 Basic settings of the model

In the economy the population consists of two classes, the high-SES class and the low-SES class, and there are two types of agents within each class, the big-weight and the small-weight. We denote the high-SES and big-weight agent as H, the high-SES and small-weight agent as h, the low-SES and big-weight agent as L, and the low-SES and small-weight agent as l. Let α be the fraction of the big-weight agents in the high-SES class, and β be the fraction of the big-weight agents in the low-SES class.

3.1 Behavioral Engel's costs (BEC)

Within each class, the agent tries to reach its preferred weight given the constraint of the relative costs of changing and maintaining the body weight it chose. The direct cost of calories expenditures is denoted as s, which today includes the labor required by the agent's work, money and time costs spent on exercise, the costs related to the availability of certain calories-expenditure facilities and environments such as the park and bicycle lanes in the community, and so on. In the modern world, s also account for the counter efforts needed in correctly processing food information, which can be significant in the face of various advertisements and manipulations made by the food industry.

It's clear that the magnitude of s will be influenced by a set of technological and social changes, such as the improvement of agricultural productivity, the invention of microwave, the developments of food supply chains, and so on. It can be negative in the traditional society in which people are paid to labor, as indicated by Philipson & Posner (1999: 4).

But regarding the agent's choice of weights, we have to take into account for the agent's income and social resource constraints. Therefore the relative costs, that is the money and non-monetary costs relative to the agent's income and social resource, may be more important. We denote $I_{H,h}$ as the income and social resource of the high-SES agent, whether it's big or small type, and $I_{L,l}$ as the income and social resource of the

low-SES agent. The relative costs which can be measured as the behavioral Engel's calories-expenditure costs, are then defined respectively for the high-SES agent and low-SES agent as

$$\bar{e}(s) = \frac{s}{I_{H,h}} \text{ and } \underline{e}(s) = \frac{s}{I_{L,l}}.$$

It is important to note that income and social resource affect not only the agent's ability to pay monetary costs but also the cognitive capacity in dealing with the non-monetary costs. As Mani, et al. (2013) show that the poor have problems in making and implementing right decisions because poverty does tax the mind.

In a similar fashion, we denote the direct cost of gaining and maintaining a big weight as f, which includes prices of foods, the time spent in the preparation at home or traffics to markets or restaurants, and all other money and non-monetary costs of calories intakes. The behavioral Engel's calories-intake costs for the high-SES and low SES agents respectively are

$$\bar{e}(f) = \frac{f}{I_{H,h}} \text{ and } \underline{e}(f) = \frac{f}{I_{L,l}}.$$

Note that while both direct costs, s and f, are identical to all agents at a certain point in time, the incomes are different for different class agents. Therefore the BEC may be different for agents of different classes.

3.2 Social division, class norm, and the intra-class competition

The agent of one class compares its weight, w, with the weight of an agent from the other class, w', and computes the social division index, $1 + \sigma^2$, where

$$\sigma^2 = (w - w')^2.$$

Therefore the bigger the σ^2, the larger the social division is. The crucial point in our argument is that different classes judge differently about this division. For the high-SES agents, the bigger the division is the better, while the low-SES agents would prefer a smaller division. This is showed in agents' value judgments of the social division, γ, which are different for different classes and multiplied with $(1+\sigma^2)$. As Veblen suggests, we assume that the high-SES agent values the division positively, with $\gamma = 1$, and the low-SES agent values the division negatively with $\gamma = -1$.

Meanwhile, as many studies showed, the magnitude of the effect of social division on the individual's well-being is strongly influenced by the individual's characteristics, such

as gender, occupation, the possibility or the desire of upward mobility, etc. We denote these characteristics as $\rho = \bar{\rho}, \underline{\rho}$ for the high- and low-SES agents respectively, and both are greater than zero. Thus, for example, the value of ρ would be larger for women than men. Therefore, the direction and the extent of the social division effects on agent's utility depend on the agent's SES and individual characteristics. This is shown as

$$\gamma\rho(1+\sigma^2).$$

Finally, given the social division, low-SES agents not only try to imitate the behaviors of high-SES agents, but also compete with each other in choosing specific weights, due to the limitations of the opportunity of upward mobility. Like in other cases of competitions for limited resources, the marginal return from maintaining a specific weight decreases as the number of agents having the same weight increases. This disutility is represented as $-\mu\beta$ for the big-weight agent and $-\mu(1-\beta)$ for the small-weight agent, in which μ is the marginal effect of the intra-class competition, and $\mu > 0$. In society of class division, this effect only occurs for low-SES agents. Furthermore, it is important to note that this intra-class competition occurs for both big and small low-SES agents, and is neutral with respect to their choice of specific weights. That is, whatever the weights being chosen, each low-SES agent suffers from the effect of competition as long as some other low-SES agents made the same choices.

Combined the information of the (dis)utilities of the social division and the intra-class competition, and the Engel's costs of calories intakes and expenditures, the payoff functions are given by:

$$\begin{aligned}
\pi_H &= \gamma\bar{\rho}(1+\sigma^2) - \bar{e}(f) \quad \text{for the high-SES big-weight agent;} \\
\pi_h &= \gamma\bar{\rho}(1+\sigma^2) - \bar{e}(s) \quad \text{for the high-SES small-weight agent;} \\
\pi_L &= \gamma\underline{\rho}(1+\sigma^2) - \mu\beta - \underline{e}(f) \quad \text{for the low-SES big-weight agent;} \\
\pi_l &= \gamma\underline{\rho}(1+\sigma^2) - \mu(1-\beta) - \underline{e}(s) \quad \text{for the low-SES big-weight agent.}
\end{aligned} \tag{1}$$

3.3 Choosing body weights

For simplicity without losing generality, let's assume the big weight is 1 and the small weight is 0, so $\sigma^2 = 0$ when meeting with the agents of the same weight, and $\sigma^2 = 1$ when meeting agents with different weights. Further assume $\mu = 1$, then the payoff matrix will be:

Table 2: The payoff matrix.

		Low-SES Player: L	Low-SES Player: l
High-SES Player	H	$\bar{\rho} - \bar{e}(f)$, $-\underline{\rho} - \beta - \underline{e}(f)$	$2\bar{\rho} - \bar{e}(f)$, $-2\underline{\rho} - (1-\beta) - \underline{e}(s)$
	h	$2\bar{\rho} - \bar{e}(s)$, $-2\underline{\rho} - \beta - \underline{e}(f)$	$\bar{\rho} - \bar{e}(s)$, $-\underline{\rho} - (1-\beta) - \underline{e}(s)$

The structure of the matrix reflects an interesting aspect of the issue faced by agents when choosing their weights in the class-divided society. From this simplified payoff matrix we can read clearly that the low-SES agents would like to choose the same types of weights as the high-SES agents they met, while the high-SES agents prefer opposite choices, leaving us no pure strategy equilibrium. This cat-and-mouse feature appears quite frequently in many other contexts that are similarly influenced by the class-cultural norms, such as choosing schools/residential communities, or the relationship between fashion leaders and followers.

At each period, the agent of one class compares the resulted payoffs between being big-weight and small-weight, given the weight distribution in the population, and then converts to the type of agent which receives a higher payoff. For example, suppose that a big-weight high-SES agent (H) finds that, given the weight distribution in the other class, the small-weight high-SES agent (h) receives higher payoff than the big-weight one. Then the agent will convert itself from H to h.

Given the weight distribution in the low-SES class, for the agents of the high-SES class the expected payoffs of choosing a big weight and a small weight respectively are:

$$v^H(\beta) = \beta\pi(H, L) + (1-\beta)\pi(H, l),$$

$$v^h(\beta) = \beta\pi(h, L) + (1-\beta)\pi(h, l).$$

A H agent would choose to become h if $v^H < v^h$, and remains as H if otherwise. Similarly, the expected payoffs for the agents of the low-SES class are:

$$v^L(\alpha) = \alpha\pi(L, H) + (1-\alpha)\pi(L, h),$$

$$v^l(\alpha) = \alpha\pi(l, H) + (1-\alpha)\pi(l, h).$$

The main focus of our analysis is the resulted choices at the group level, i.e., the resulted fractions of big-weight agents in each class, which can be captured by utilizing the replicator dynamic equations as follows.

Based on the behavioral rules specified above, the fractions of the big-weight agents in the high-SES class in the next period, α', is:

$$\alpha' = \alpha + (1-\alpha)\eta^H(v^H - v^h) - \alpha\eta^h(v^h - v^H),$$

where $\eta^h = 1$ if $v^h > v^H$ and is zero otherwise, and $\eta^H = 1$ if $v^H \geq v^h$ and is zero otherwise. $\eta^h + \eta^H = 1$. The second term of this equation indicates the small-weight agents who would convert to the big-weight, and the third term indicates the big-weight agents who would cease to be the big-weight. Similarly, we can calculate the fraction of the big-weight agents in the low-SES class in the next period, β':

$$\beta' = \beta + (1-\beta)\eta^L(v^L - v^l) - \beta\eta^l(v^l - v^L).$$

Then the changes in the fractions of high-SES big agents and low-SES big agents are given by the following replicator dynamic equation for α and β:

$$\begin{aligned} \Delta\alpha &= \alpha' - \alpha = ((1-\alpha)\eta^H + \alpha\eta^h)(-\bar{\rho}(2\beta - 1) + \bar{e}(s) - \bar{e}(f)). \\ \Delta\beta &= \beta' - \beta = ((1-\beta)\eta^L + \beta\eta^l)(\underline{\rho}(2\alpha - 1) - 2\beta + 1 + \underline{e}(s) - \underline{e}(f)). \end{aligned} \tag{2}$$

It's easy to see that in this system there is one focal point (α^*, β^*) by letting $\Delta\alpha = 0$ and $\Delta\beta = 0$:

$$(\alpha^*, \beta^*) = \left(\frac{1}{2} - \frac{\underline{e}(s) - \underline{e}(f) - 2\beta + 1}{2\underline{\rho}}, \frac{1}{2} + \frac{\bar{e}(s) - \bar{e}(f)}{\bar{\rho}}\right),$$

when $v^H = v^h$ and $v^L = v^l$. Due to the strategic nature of the weight-choosing behaviors in this class-divided society, the fraction of big-weight high-SES agents α^* is negatively influenced by the low-SES agents' choices of being big, under the effects of Engel's costs, individual characteristics and the intra-class competition. One the other hand, the fraction of big-weight low-SES agents β^* is determined in the similar way, but without the intra-class competition and with a positive sign, showing the willingness to choose the same weights as the high-SES agents.

Further check the properties of this system, we get

$$\frac{\partial\Delta\alpha}{\partial\beta} = -2\bar{\rho}(1-\alpha)\eta^H - 2\rho\alpha\eta^h < 0,$$

which shows that the fraction of high-SES agents who choose big weights will decrease if there are more big-weight low-SES agents. And

$$\frac{\partial\Delta\beta}{\partial\alpha} = 2\underline{\rho}(1-\beta)\eta^L + 2\rho\beta\eta^l > 0,$$

which shows that, in contrast, the fraction of low-SES agents who choose big-weight will increase if there are more big-weight high-SES agents. These patterns can be captured in the following phase diagram, in which the upward sloping $\Delta\beta = 0$ curve is given by

$$\frac{d\alpha^*}{d\beta} > 0,$$

which is resulted from the intra-class competition among low-SES agents.

In this system the streamlines will inwardly twirl toward the equilibrium point (α^*, β^*). It's not difficult to show that this system also satisfies the Kolmogorov conditions of stability (Nowak, 2006: 66-68), confirming that the unique focal point (α^*, β^*) is a stable equilibrium.

4 Comparative statics

We are now ready to analyze the changes of the equilibrium fractions over time by incorporating plausible changes in the costs of calories intakes and expenditures.

First, by plugging β^* into α^*, we get

$$\alpha^* = \frac{1}{2} - \frac{\underline{e}(s) - \underline{e}(f)}{2\underline{\rho}} + \frac{\bar{e}(s) - \bar{e}(f)}{\underline{\rho}\bar{\rho}} \text{ and } \beta^* = \frac{1}{2} + \frac{\bar{e}(s) - \bar{e}(f)}{\bar{\rho}}.$$

Next, let's simplify the trajectory of social development into the two-period comparison, the traditional and the modern ones. In the traditional society, due to the underdevelopment of technology, the production and processing of foods are generally much costly while the life style requires more labor on average. So we expect the direct cost of calories intake to be larger than the direct cost of calories expenditure, i.e., $f > s$. Given the high-SES agents have higher incomes than the low-SES agents such that $I_{H,h} > I_{L,h}$ being the general case, it would be plausible that $\bar{e}(s) < \underline{e}(s) < \bar{e}(f) < \underline{e}(f)$ in the traditional society. Therefore, we have

$$\frac{\underline{e}(s) - \underline{e}(f)}{2\underline{\rho}} < 0, \text{ and } \frac{\bar{e}(s) - \bar{e}(f)}{2\bar{\rho}} < 0, \text{ while } \frac{\bar{e}(s) - \bar{e}(f)}{\underline{\rho}\bar{\rho}} < 0$$

but is small in the absolute term when $\underline{\rho}\bar{\rho}$ is sufficiently large.

These conditions give rise to the result as

$$\alpha^* > \frac{1}{2} > \beta^*,$$

which predicts that the fraction of big-weight agents in the high-SES class will be larger than the fraction of big-weight agents in the low-SES class. Referring back to our phase

diagram, the resulted (α^*, β^*) in the traditional society will be located at the right lower part of the diagram.

In contrast, in the modern society, since there are significant efficiency improvements in the food system and changes in the work and life styles, we expect the cost of calories intake will be less than the cost of calories expenditure, i.e., $f < s$. Given the incomes, we would have $\underline{e}(s) > \bar{e}(s) > \underline{e}(f) > \bar{e}(f)$ in the modern society. Therefore

$$\frac{\underline{e}(s) - \underline{e}(f)}{2\underline{\rho}} > 0, \text{ and } \frac{\bar{e}(s) - \bar{e}(f)}{2\bar{\rho}} > 0, \text{ while and } \frac{\bar{e}(s) - \bar{e}(f)}{\underline{\rho}\bar{\rho}} > 0$$

but is reasonably small. This predicts that in the modern society,

$$\alpha^* < \frac{1}{2} < \beta^*,$$

in which the fraction of big-weight agents in the low-SES class will be larger than in the high-SES class.

The results generated from our model are consistent with the empirical patterns documented widely in the literature.

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