1 Introduction

Alarming statistics on the growth of obesity in the United States (and, more recently, in other countries as well) have been widely publicized in recent years. Obesity has become the object of grave concern among public health officials, and has spawned voluminous research in the fields of medicine and public health. Concern has focused on understanding obesity medically, as well as on the cost of obesity-related morbidity and mortality, in both economic and human terms (Hassan et al. 2003; Himes 2000; Hamermesh and Biddle 1994; Cawley 2004; Pagan and Davila 1997). The level of alarm has become so pronounced as to have already spawned a backlash.[1] While average weights increased steadily, suggesting a rightward shift of the weight distribution, perhaps the most dramatic development is the growth in the upper tail. Among women, for example, the 95th (99th) percentile weight moved from 215 (258) pounds in 1976-80 (NHANES II) to 251 (305) pounds in 1999-2000 (NHANES 99), while over the same period average weight increased from 148 to 168 pounds, as shown in Table .[2,3] The official definition of obesity employed by the Centers for Disease Control (CDC) and by the World Health Organization (WHO) is a body mass index (BMI) value of 30 or greater, where BMI is the ratio of weight, measured in kilograms, to squared height, measured in meters. For a woman 5'4" tall, a weight of 175 pounds or greater classifies as obese, and for a man 5'9" tall, the obesity weight

[1]For example the group Consumer Freedom (consumerfreedom.com) has criticized the emergence of food cops who seek to impose "twinkie taxes" on fattening foods and otherwise regulate food intake.

[2]Changes of similar magnitude are observed in the BRFSS data between 1990 and 2002 as shown in Table 1 and Figure 5. For men, 95th (99th) percentile weight increased from 230 (264) to 277 (338) pounds, and the average increased from 177 to 192 as shown in Table (see Figure 6 for men).

[3]The empirical findings presented in this paper are based on samples of 30 to 60 year-old Americans from two surveys administered by the Centers for Disease Control and Prevention: The Behavioral Risk Factor Surveillance System (BRFSS) and wave II, II and 99 of the National Health and Nutrition Examination Survey (NHANES II, III, and 99). The BRFSS is an exceptionally large random sample of the resident population 18 years and older in participating states of the US. Self-reported information on actual weight, desired weight and demographic characteristics is gathered in cross-sections between 1990 and 2002 (1994-2002 for desired weight). We correct for potential bias of self-reported weights (see Villanueva 2001) following the approach by Chou et al. 2004 using NHANES III data for the 30-60 year olds. NHANES II, III, and 99 collects information from medical examinations on weight and health status of a cross-section of the US population in 1976-1980, 1988-1994, and 1999-2000. Combining the data from these two sources allows us to track changes in the distribution of weight and BMI by demographic characteristics between 1976-80 and 2002.

threshold is 203 pounds.[4]

A number of recent papers in economics have sought to explain rising obesity rates among adults. The explanations have focused naturally on standard economic influences such as falling food prices and preparation time costs, and reduction in physical labor on the job (Chou et al. 2004; Cutler et al. 2003; Philipson and Posner 1999, Lakdawalla and Philipson 2002). While these models can predict a general secular trend toward rising weight levels (Philipson and Posner), and offer a suggestive theory (Cutler et al.) to explain growth in the upper tail, none attempts to make predictions of the dynamics of the overall weight distribution. These models tend toward simplistic representations of the biological aspects of weight gain, and essentially ignore social influences.

We show that a biologically sophisticated, agent-based model, involving mutual feedbacks between individual behavior and an endogenous body weight standard, can explain the dramatic growth in the upper tail of the weight distribution over the past 30 years. Individuals in the model derive utility from food and non-food consumption, and disutility from deviating from the social weight standard. Consumption preferences are identical, but individuals differ in their genetic endowments of metabolism, and so arrive at different weights when facing similar prices and income. The equilibrium distribution of weights and the equilibrium weight norm that emerge depend on three key factors: the distribution of metabolic rates in the population; the rule relating the weight norm to the empirical weight distribution; and relative food prices. Employing an explicit and scientifically grounded description of human metabolic variation, we calibrate the choice model to women in the 30-60 year old age bracket. Consistent with the empirical evidence, simulations of this model predict substantial growth in the upper tail (95th percentile weight) of the weight distribution, and more modest increases in average and median weight, in response to falling food prices.

Recent economic explanations have emphasized the role of falling prices in the obesity epidemic,

[4] BMI values between 18.5 and 24.9 are considered "healthy", BMI less than 18.5 is "underweight", and BMI between 25 and 29.9 is "overweight" but not obese. BMI thresholds of 35 and 40 are used to classify increasingly severe degrees of obesity. The thresholds are based on correlations with morbidity and mortality risk (Kuczmarski and Flegal 2000). Several websites offer simple BMI calculators. See e.g., http://www.cdc.gov/nccdphp/dnpa/bmi/.

where price may or may not include the time cost of preparation (Chou et al., Cutler et al., Lakdawalla and Philipson). Prices of many food items such as chicken and beef have fallen considerably relative to the average price of all consumer goods since 1980 (see Figure 1). While earlier data on selected items were not available, data on the relative price of food-at-home and food-away-from-home show a decline since the 1970s (see Figure 2). The CPI-based indices do not measure the time preparation costs of food, however, so an estimate of trends in the full cost of food consumption cannot be readily ascertained. Cutler et al. (2003) find considerable declines in meal preparation time costs, and argue that these declines, rather than falling food prices, are the more likely explanation for the recent increases in caloric consumption and obesity.

A price decline plays an important role in our own examination of recent weight trends, but we do not differentiate between sources of decline in the full food price. Rather than identifying different types of price effects on behavior, we are concerned with the interdependency of market, social, and biological forces in the determination of body weight. This inquiry emphasizes the effect of exogenous price changes on weight norms, but the model also implies that weight norms themselves influence food prices, and therefore have important general equilibrium implications. We hold nominal income constant across individuals and over time, but the price declines will imply increasing real incomes. This pattern agrees with the long-term trend in real per-capita disposable income since 1970 (www.bea.gov).[5]

In addition to the quantities of food and other consumption, individual utility in the model depends on weight relative to a social weight standard or norm. While the existence of weight standards may seem like an obvious social fact, there is no general scientific consensus on how they are formed. While recent research in sociobiology (Singh 1993, Pinker 1999) finds evidence that male preferences over

[5]There is cross-sectional evidence of a modest negative relationship between income and body mass index (Chou et al. 2004). However, the income gap in obesity prevalence has narrowed over time (Maheshwari et al. 2005). Changes in the income distribution, for example growing inequality, may have contributed to changes in the weight distribution. A complete understanding of income effects would require a model of the choice of food quality, which–to our knowledge–has not been proposed yet and is beyond the scope of the current paper. By abstracting from income differences across individuals we can focus on the assessment of other potential explanations of the variation in body weight.

female waist-to-hip ratios (WHRs) are roughly uniform across cultures and over time, the same research recognizes significant historical and cultural differences in concepts of ideal weight and other aspects of physique.[6] Such ideals are typically inferred from the study of popular imagery such as paintings, sculpture, and, more recently, magazines, television, and movies (Garner 1980). While such idealized images have been shown to affect individuals' self-assessments and aspirations (Harrison 2003), people are also concerned with being "normal" in relation to others with whom they interact (Bandura 1986, Dwyer et al. 1970). At the same time health professionals and governments promulgate standards indicating "healthy" weight levels by height and gender, as embodied in the BMI thresholds described above. Weight standards are enforced through a number of channels, including selection in marriage markets and job markets as well as through psychological internalization (Ross 1994), and the strength of such enforcement might vary across social groups (Burke and Heiland 2005). Therefore a given individual's weight aspiration is subject to a number of cultural and social influences, and need not in general conform to the physical ideals depicted in popular media.

Our model of weight norms aims to capture, to a rough approximation, the net result of such influences in a contemporary Western context. The model assumes that all individuals in a given social group aspire to the same weight standard, defined as a fraction, less than one, of average weight in the population. Therefore the standard is subject to change if, for example, prices affect average weight. This specification, in which people aim to be thinner than the average person in the reference population, combines two basic assumptions: (1) that in contemporary Western society thinness (up to a point) is prized (Garner 1980, Mazur 1986), and (2) that individuals assess themselves in relation to others rather than against an absolute scale. Note that the latter assumption creates room for gaps between the prevailing Western ideal of thinness and the de facto standards against which individuals are judged. Thus ours is not a model of the evolution of the media ideals themselves.

The idea that norms and standards reflect changes in aggregate behavior and are therefore flexible,

[6] The evolutionary explanation is that female waist-to-hip ratio is a better predictor of reproductive fitness and health among women than body weight or breast size, and therefore selection pressure should have been particularly strong on preferences over WHR.

at least in the long run, is standard in sociology and anthropology. While Veblen (1994 [1899]) and other early institutional economists also took this view, it has only relatively recently been given formal expression within economic models, such as in Becker and Murphy's (2000) model of social capital, and in Frank's discussions of social norms (Frank 1999). The relative nature of self-assessment in general has been validated by Easterlin (1974), who found that self-reported happiness was much more dependent on relative rather than absolute wealth. For purposes of comparison, however, we also analyze the case in which the weight standard is fixed. This case is relevant because the adjustment of social norms is likely to take time to play out, and because prior models have posited a fixed exogenous weight standard (Philipson and Posner 1999, Levy 2002). We find that the differences between a fixed norm model and a flexible norm model are not only quantitative, in terms of the effect of price declines on weight, but also qualitative in terms of the welfare effects of price changes. The long term implications of these differences are potentially quite large, and there is evidence to suggest that the long-run, i.e. the time it takes for norms to adjust, is not very long at all.

Despite the casual observation that celebrities and models are thinner than ever, there is evidence to support the notion that the weight levels to which Americans actually aspire have increased. This evidence comes from the CDC's Behavioral Risk Factor Surveillance Survey (BRFSS), which contains self-reported "desired weight" values in addition to self-reported actual weights for the same individuals. While the data are not longitudinal, observations from different survey years are instructive of overall trends.[7] In 1994 average weight for an American woman was 147 pounds, and the average desired weight among women was 132 pounds. By 2002 the average had increased to 153 pounds, and average desired weight had increased as well, to 135 pounds. Similarly for men over the same time period, average desired weight increased by 3 pounds while actual average weight increased by 6 pounds. Observing the relationship between actual and desired weights for women by ethnicity, race, and by state, we find that average desired weight within a given group is typically about 12% below

[7] There is no guide for correcting desired weight values since these are inherently subjective. Therefore for consistency we use the uncorrected (self-reported) values for desired and actual weight in Figures 3 and 4. However, corrected values of the numbers we report are available on request.

the actual average weight for the group (see Figure 4), with some small but systematic variation in this percentage across groups. For men, desired weights are on average only 5% below average actual weight. Expressed in terms of BMI instead of weight, Figure 3 illustrates the relationships between desired and actual values for men and women, aggregating over the 1994 and 2002 BRFSS data. These observations inform some of the simulation exercises, in which we examine the effect of changes in the fraction below average weight that individuals target.

The remainder of the paper is organized as follows. Section 2 describes the theoretical model and the comparative static effects of price on equilibrium weights and the equilibrium weight norm. Section 3 describes the numerical simulations of the equilibrium weight distributions for various price levels and model specifications. Section 4 concludes and discusses policy implications.

2 Theoretical Framework

2.1 Agent-Based Model

The theoretical model takes an agent-based approach, positing heterogeneous individuals interacting within a social group. The nature of the interaction is that each individual compares her own weight to the group's commonly-held norm or "reference" weight, and this comparison enters her optimization problem as described below. The reference weight itself is some function of the group's weight distribution, and is therefore subject to change over time. The assumption of a common (relative) weight norm is admittedly highly stylized, and we recognize that individual weight aspirations are likely to exhibit idiosyncratic variation.[8] The model is applied primarily to American women in the 30-60 age group observed over the past 30 years. In the BRFSS data for 30-60 year old women, the coefficient of variation of desired weight is 13.9%. However, the coefficient of variation of actual weight is sig-

[8] One likely source of such variation is height. For a discussion of why we use a weight norm rather than a BMI norm that adjusts for height see page 12 below.

nificantly greater, at 23.1%.[9] In addition race is a significant explanatory factor in desired weight for this sample. These facts suggest the presence of a social component in the formation of weight aspirations. The model focuses exclusively on this social component, and assumes that the demographic under consideration constitutes a single social group. As such it is likely to generate less variation than a model with idiosyncratic preference shocks or multiple subgroup-specific weight targets. This approach therefore constitutes a conservative test of the explanatory power of social weight norms.

Equilibrium for the system is defined as a weight distribution and a norm that are mutually consistent. Each individual maximizes a myopic utility function over short-term food and non-food consumption taking the reference weight and prices into account.[10] Food and non-food consumption are both goods, but deviation from the reference weight is a bad. A general expression of the one-period utility model is as follows:

$$U_{it}[F_t, C_t | W_{t-1}] = G_i[F_{it}, C_{it}] - J(W_{it}[F_{it}, W_{i,t-1}, \varepsilon_i] - M_{t-1})^2. \tag{1}$$

F_t and C_t represent food and non-food consumption for period t, respectively. W_{t-1} is weight at the end of period $t-1$, which is a product of past actions. Individual heterogeneity is captured by ε_i, which is a stationary shock to basal metabolism described below. G_i is the norm-independent component of utility: it is strictly increasing and strictly concave in C, and strictly concave but not necessarily monotonic in F. The term beginning with J gives the social-interaction component, which is the cost of deviating from the reference weight, M. The subscript on M indicates that agents observe the value of M at the end of period $t-1$ and take this as fixed in the optimization; in particular they do not forecast the value of M that will emerge as a consequence of aggregate behavior in period t. The coefficient J gives the strength of the social interactions, which is held constant across individuals. The presence of a norm has the intuitive effect of lowering the variance of weight in the population, even though not everyone conforms to the norm exactly.

[9] For men the corresponding figures are 13.7% and 18.6%, respectively.

[10] We will refer to the reference weight alternatively as the norm or the target.

The individual correctly anticipates her own end-of-period weight as a function of food intake, and so takes into account the effect of current food consumption on the cost of deviating from the reference weight. This cost is symmetric–it is just as undesirable to be underweight relative to the norm as overweight– and is meant to capture several known types of sanctions. Stigmatization of overweight (and underweight) individuals is well-documented (Myers and Rosen 1999), and may entail for example teasing, ostracism, and discrimination in hiring. Peer pressure and contagion regarding eating behavior has also been observed, particularly among adolescent girls (Crandall 1988). Ross (1994) has emphasized depression as a consequence of overweight. She identifies three causes of depression among the overweight, two of which relate directly to the presence of socially derived weight norms. For example she finds that some overweight individuals become depressed as a direct result of negative self-perception, and that these individuals tend to belong to social groups within which overweight is rare. Ross also identifies chronic dieting as a source of depression among overweight individuals striving to conform to a thin norm. In addition, she finds that the physical health consequences of overweight, such as diabetes and reduced mobility, constitute a separate source of depression among the overweight.

In addition to mental health costs, extreme overweight and underweight entail significant physical health consequences. Several studies have shown, for example, that the risks of diabetes, heart disease, osteoarthritis and other health conditions accelerate with increases in body mass index (e.g., Must et al. 1999). In addition, mortality exhibits a U-shaped relationship to BMI among men in the U.S., indicating that underweight imposes similar mortality risks as overweight (Troiano et al. 1996). Evidence from developing countries, where underweight is much more prevalent, indicates substantially elevated disease incidence among low weight (BMI below 20) individuals (Ezzati et al. 2002). A model with deviation costs that depend on a mutable norm will capture these health costs only when the value of the norm lies within the medically recommended range. In the parameterizations we consider the emergent norms do in fact fall within this range, but in general the model does not constrain them to do so. The health costs of obesity in particular are partly reflected in the increased per-capita health spending among the obese relative to the normal weight population (Thorpe et al. 2004). In addition to psychological and physical costs, there are direct economic costs associated with overweight and obesity. For example, among younger white females (age 16-44) in the U.S., an increase in weight of two standard deviations has been shown to reduce the average wage by 9% (Cawley 2002).[11]

Successive optimization of the one-period problem implies convergence to a stable weight for any given value of M. This weight does not in general coincide with the stable weight that optimizes an infinite horizon problem in which one-period utility is given by $U[.]$. The myopic specification may be taken to imply some lack of self-control, although we do not explicitly model a time inconsistency problem, as do Cutler et al. (2003). We believe the model is behaviorally plausible: individuals give some thought to the effects of calorie consumption on weight, but without full consideration of the lifetime implications. While Cutler et al. (2003) offer a qualitative explanation for growth in the upper tail of the weight distribution on the basis of variation in the severity of the self-control problem, the heterogeneity in our model arises on the basis of known variation in human metabolic rates, as discussed below.[12]

For purposes of simulation and calibration we specify the maximization problem as follows:

$$Max_{\{F_t,C_t\}} U_{it}[F_t, C_t | W_{i,t-1}, \alpha, \delta, \beta, J, \gamma, \rho, \varepsilon_i, M_t] = \tag{2}$$

$$\alpha F_{it} - \delta F_{it}^2 + \beta log[C_{it}+1] - J(W_{i,t-1} - (7/3500)(\gamma + (\rho + \varepsilon_i)W_{i,t-1}) + .9F_{it} - M_t)^2,$$

$$s.t. \quad p_t F_t + C_t \leq Y$$

Within the single period, calibrated to one week, the marginal utility of food, F, declines and eventually becomes negative. The expression inside the parentheses following J just amounts to the difference

[11]The results in Cawley (2002) and in Averett and Korenman (1996), based on recent U.S. samples, show weight-related earnings penalties only for overweight and obese individuals. Since the incidence of underweight in the U.S. is limited these findings do not rule out the possibility of equivalent economic costs among underweight subjects.

[12]There is strong evidence that self-regulation of food intake is driven in part by biological factors (see for example Gale et al. 2004, and Spiegelman and Flier 2001). If low self-control is correlated with low metabolism the explanations may be mutually reinforcing.

between end-of-period weight W_t, and M, as in equation (1).[13]

In this version of the model metabolism is linear in body weight, and the short-term relationship between food intake and weight (2) is:

$$W_t = W_{t-1} - (7/3500)(\gamma + (\rho + \varepsilon_i)W_{t-1}) + .9F_t. \qquad (3)$$

Calories burned per day, not including those burned in digestion, is given in the above by the terms $\gamma + (\rho + \varepsilon_i)W_{t-1}$. This weight-linear specification is due to Schofield (1985), and has been used in Cutler et al. and others. We discuss the merits and limitations of this model below. We multiply calories per day by 7/3500 to convert to pounds of body weight expended per week, based on the fact that burning 3500 calories implies loss of one pound of body weight. F_t is total food intake for the week, measured as calories divided by 3500, or the equivalent of the caloric intake in pounds of body weight.[14] Since digestion of a given amount of food requires on average 10% of calories consumed, we multiply by .9 to get food intake net of digestive metabolism (Schofield 1985). Aside from the calories burned in digestion, we assume for simplicity that calorie expenditure is limited to the basal metabolic rate (BMR), or the calories needed only to sustain basic bodily functions such as lung and heart activity with the body at rest. The advantage of this assumption is that BMR is exogenous. Of course, variation in physical activity also contributes to variation in metabolism and therefore weight. By abstracting from endogenous physical activity we assume that the number of actual calories burned is strongly correlated with BMR. We assume that individuals correctly perceive both their food intake and this metabolism function.[15]

The linear model of BMR in weight is based on empirical measurement and estimations by Schofield et al. (1985). The estimated parameters are gender and age-group specific, and our simulations will use

[13]This social interaction term is similar to those in Glaeser and Scheinkman (2002), Brock and Durlauf (2001), Burke and Prasad (2003), and Becker and Murphy (2000), among others.

[14]This is not the same as pounds of food consumed, because the caloric value of food depends on more than its weight.

[15]There is evidence that people systematically underestimate their caloric intake (Wansink 2004), but we ignore this problem in the current paper.

the estimates for women in the 30-60 year old age group.[16] As suggested by Leibel et al. (1995) and Rand (1982), however, we make the disturbances proportional to weight: the shock ε_i is normally and identically distributed with mean zero and standard deviation σ_ε. Because the shock is multiplied by weight the errors are heteroscedastic by weight class. Unlike the homoscedastic case, this specification implies an asymmetric equilibrium weight distribution, with a long upper tail mirroring the general shape of the weight distributions observed in the BRFSS and NHANES data.

We do not model height explicitly here, but the specification does not rule out variation in heights across individuals. We choose to abstract from height differences for a number of reasons. First, Schofield argues that individuals of different height and the same weight have the same BMR on average. In addition the Schofield residuals are not heteroscedastic in height, even though the distribution of height varies by weight. Most importantly, average heights for women in the United States increased by approximately 3 centimeters, or less than 2%, over the last four decades (see e.g., Komlos and Baur 2003). Although we claim the model need not imply constant heights across individuals, we express the common norm as a weight value rather than a body mass index (BMI, defined above) value which adjusts for height. While the BRFSS data do indicate variation in individual desired weights with actual weight, the values do not vary sufficiently in height to render desired values of BMI constant across individuals. In fact the desired BMI values implied by the BRFSS data decrease systematically in height. Thus a model positing a common desired BMI value is not necessarily more realistic than one involving a common weight norm.[17]

While the Schofield equations have become a de facto standard for predicting BMR, some aspects of the estimates have come into question by Horgan and Stubbs (2003) and Pullicino et al. (1996). The former showed that the Schofield equations substantially overestimate BMR for the obese, a problem

[16] Cutler et al. (2003) also reference the Schofield model, but it is not clear which model or age group for women they consider. When we convert the Schofield values, measured in megajoules per day, into calories per day, we do not reproduce the coefficients stated for women in Cutler et al. (2003).

[17] Anecdotal evidence suggests that weight values are more focal than BMI values, especially given the complexity of computing BMI. Interestingly the study of Playboy models mentioned above found that their weights have remained constant since 1950 at the same time as their heights have increased significantly.

due in part to the dearth of obese subjects in the Schofield data. Drawing on these findings we also run our model for a weight-BMR relationship that is quadratic in weight, such that BMR per unit of body weight declines in weight. Again the idiosyncratic shocks are multiplicative in weight, but do not affect the coefficient on weight-squared.[18] The quadratic relationship between weight and metabolism we adopt is as follows:[19]

$$\text{Kcal per day} = \gamma + (\rho + \varepsilon_i)W - .001W^2. \tag{4}$$

3 Definition of equilibrium

Individuals in the population are identical in all of the parameters of the utility function, α, β, ρ, γ, J, M, have identical incomes, and face the same prices. The only explicit source of heterogeneity is the idiosyncratic metabolic shock, ε_i. The full equilibrium conditions under the linear metabolism model can be expressed as follows:[20]

$$\alpha - 2\delta F_i^S - 1.8J(W_i^S - (7/3500)(\gamma + (\rho + \varepsilon_i)W_i^S) + .9F_i^S - M^S) = \lambda p, \tag{5}$$

$$F_i^S = (1.11)(7/3500)(\gamma + (\rho + \varepsilon_i)W_i^S), \tag{6}$$

$$M^S = \zeta(\frac{1}{N}\sum_i W_i^S), \tag{7}$$

[18]At the current time, however, there appears to be no general consensus as to the best model of BMR fitted to the entire weight distribution, and there have been few attempts to estimate this relationship among large representative groups. Evidence suggests that predicting BMR for higher values of weight requires also a measure of the body composition in terms of fat vs. lean body mass (Pullicino et al. 1996). Our model does not explicitly describe the composition of body weight, but the quadratic specification is consistent with the finding that overweight individuals tend to have excessive body fat rather than excessive muscle (Pullicino et al. 1996).

[19]Eventually as weight increases, the quadratic model implies that metabolism declines in absolute terms with weight. Such declines have not been observed empirically, and thus the model becomes less accurate for very high weight levels. While the threshold at which metabolism begins to decline is lower the slower is individual metabolism, in the simulations only a small group of very low metabolism individuals ever experience decreasing metabolism. Nonetheless for our parameter choices and distributional assumptions, everyone converges to a stable weight in every experiment.

[20]Equilibrium conditions for the quadratic metabolism model are equivalent but analytically less transparent, so we use the linear specification here for ease of exposition.

$$\frac{\beta}{C_i^S+1} = \lambda, \tag{8}$$

$$pF_i^S + C_i^S = Y_i. \tag{9}$$

The conditions apply to an interior equilibrium, in which stable food intake, F_i^S, stable weight, W_i^S, and stable non-food consumption, C_i^S are all strictly positive. M^S is the equilibrium weight norm, which according to equation (7) is some fraction, ζ, of the average stable weight that arises under this norm. Equation (5) gives the first-order condition on food consumption, where λ is the Lagrange multiplier. Equation (6) guarantees that per-period food intake maintains weight at the level W_i^S. Equations (8) and (9) are, respectively, the first order condition on non-food consumption and the budget constraint. The equilibrium norm depends on the relative price of food, the distribution of individual shocks, and the magnitude of J, because these determine the stable individual weights and consumption levels for any fixed M. The equilibrium norm (and therefore the weight distribution) also depends on ζ, which we will set at .85, .88, and .95 in various simulations. Equilibrium depends on income levels and the remaining parameters as well, but we hold these fixed throughout the analysis.

Assuming the shocks are normally distributed, the expected value of the equilibrium norm is defined implicitly as a function of prices by the following equation, in which $\phi(.)$ represents the standard normal density function:

$$M^S(p) = \zeta \int_{-\infty}^{\infty} W_i^S(M^S(p), p, \varepsilon_i)\phi(\varepsilon_i/\sigma_\varepsilon)d\varepsilon. \tag{10}$$

It should be noted that because the absolute shocks are heteroscedastic in weight, the expected average weight in equilibrium does not correspond to the stable weight for the individual that draws $\varepsilon_i = 0$.

Under our functional form and parameters, an interior equilibrium exists and is unique for each realization of the metabolic shocks. The existence and uniqueness of a (stable) equilibrium norm follows from two (necessary and sufficient) properties of the model: (1) each individual has a unique stable weight for every possible value of M; and (2) the rate of change of the stable weights with M is positive and less than one. The existence and uniqueness of a stable weight for a given M and ε_i depends in turn on three necessary and sufficient conditions: (1a) a unique solution to the one-period problem exists for each starting weight; (1b) optimal caloric intake decreases (increases) as one's initial weight gets farther above (below) the target weight or norm; and (1c) the total number of calories burned per day is strictly increasing in weight for each individual, at a rate less than one.[21] The stable weight solves the one-period problem when the initial weight happens to be the stable value, but it is not in general the individual's optimal stable weight.[22] From any initial state of the system, convergence to the stable weight for any value of M, as well as convergence to the equilibrium M for given parameters, are both guaranteed. We provide verification of these assertions in the mathematical appendix.

3.1 Comparative statics and the social multiplier

Before turning to the experimental results it will be useful to describe the effects of the central parameters, namely p and J, on individual and aggregate behavior in equilibrium. First consider the effect of a change in the price of food on equilibrium outcomes. In particular we have in mind a decrease in the price of food caused by an outward shift in the food supply curve, reflecting a decline in food production and preparation costs (as in Philipson and Posner 1999 and Cutler et al. 2003). At the individual level, price has both direct and indirect effects. The direct effect is the change in stable weight holding the norm fixed. However, given that each individual adjusts her weight in response to the price change, the norm must be updated. But the norm change in turn sets off additional changes in weights, until a new equilibrium is reached. The latter is an example of a "social multiplier" effect, as in Becker and Murphy (2000), Glaeser and Scheinkman (2002), Brock and Durlauf (2001), and Burke and Prasad (2003). The total effect is expressed as the decomposition of these two effects as follows:

$$\frac{dW_i^S}{dp} = \frac{\partial W_i^S}{\partial p} + \frac{\partial W_i^S}{\partial M}\frac{dM^S}{dp}, \tag{11}$$

[21] Sufficient condition (1c) may be violated in the quadratic model for individuals with extremely low metabolic shocks (see Footnote 16).

[22] The optimal stable weight would maximize one-period utility subject to the constraint that weight be unchanged during the period.

where the expression $\frac{dM^S}{dP}$ refers to the change in the equilibrium norm caused by the price change. The first term is negative: it is optimal to eat more, and therefore weigh more, the cheaper is food, ceteris paribus. As weights rise so does any positive function of the average, and weight always moves directly with the target weight M (that is $\frac{\partial W_i^S}{\partial M}$ is strictly positive). Therefore the social multiplier effect reinforces the price effect, guaranteeing that the equilibrium weights and the equilibrium norm are decreasing in price, that is $\frac{dW_i^S}{dp} < 0$ and $\frac{dM^S}{dP} < 0$.

Similarly we can decompose the price effect on the equilibrium norm as follows:

$$\frac{dM^S}{dp} = \frac{\zeta}{N}\sum_i\left(\frac{\partial W_i^S}{\partial p} + \frac{\partial W_i^S}{\partial M}\frac{dM^S}{dp}\right) = \frac{\frac{\zeta}{N}\sum_i \frac{\partial W_i^S}{\partial p}}{1 - \frac{\zeta}{N}\sum_i \frac{\partial W_i^S}{\partial M}}. \tag{12}$$

The numerator in the last expression on the right represents the effect on the norm caused by the partial price effects on individual weights. The denominator, which is always less than one, represents the social multiplier effect on the norm: the partial price effects are amplified by the factor $1/(1-m)$, where $m = \frac{\zeta}{N}\sum_i \frac{\partial W_i^S}{\partial M}$ is the so-called "social multiplier," following Becker and Murphy (2000). The social multiplier in this context is simply the average (multiplied by the factor ζ) of the partial effects of the norm on stable weight, which in our model are uniformly positive and strictly less than one (refer to the Mathematical Appendix for exposition).

Becker and Murphy (2000, p. 15) assert the following with respect to social interactions: "The social multiplier, and the likelihood of a large response to a common change, increases as the influence of a group over its members rises." In general the literature on social interactions has reiterated the prediction that small differences in fundamentals, including prices, will lead to large differences in outcomes, and larger differences the greater the degree of social complementarity. However, a formal analysis of the variation in price effects with the strength of social influence yields a surprising result: while the social multiplier does indeed increase with the strength of social complementarity, the equilibrium response to a price change might actually *decrease* with the degree of social influence among group members. In the terms of our model, it can be shown that the effect of J, the term indicating the strength of social influence, on the price effects described in equations (11) and (12), is ambiguous. The ambiguity arises because strong social influence makes weight relatively insensitive to price, all else constant. And so, despite the fact that the larger J implies a larger social multiplier, it also implies a smaller effect to be multiplied. In terms of equation (12), an increase in J reduces the denominator but simultaneously lowers the numerator. Simulations will provide an example in which a larger J leads to smaller, rather than larger, responses of equilibrium outcomes to price changes.

We have assumed that the initial price change is exogenous to the model. However, the social multiplier effect represents an outward shift in the food demand curve. To restore equilibrium the price of food would have to increase relative to its value after the initial decline. We do not in the current framework include a model of food supply, and so do not derive the final equilibrium price explicitly. Unless the multiplier effect is very large relative to the partial price effects and food supply is highly inelastic, however, it is not likely that the demand shift will push the price higher than its original equilibrium value. Assuming the final equilibrium price is in fact lower than the original equilibrium price, it is readily shown that weight gain is still greater in an endogenous norm model than it would be in the absence of multiplier effects.

3.2 Welfare effects of price changes

Consumer welfare in our model depends only on weight relative to the flexible social norm, regardless of how this norm compares to a healthy weight standard. Thus the welfare effects of price changes are potentially quite different than welfare effects for a consumer that compares her weight to a fixed health standard. A model of the latter type of consumer would simply hold the norm fixed at some healthy weight value. By separating out the welfare effects of a price decline holding the norm fixed from the welfare effects induced by changes in the equilibrium norm, we can compare the welfare implications of our model to those in a model emphasizing the absolute costs of weight gain. To do this we decompose the total welfare effect of a price change in our model as follows:

$$\frac{dV^S}{dp} = \left[\left(U_W + U_F \frac{dF^S}{dW^S} \right) \frac{\partial W^S}{\partial p} + U_C \frac{\partial C^S}{\partial p} \right] + \left[\left(U_W + U_F \frac{dF^S}{dW^S} - pU_C \frac{dF^S}{dW^S} \right) \left(\frac{\partial W^S}{\partial M} \frac{dM}{dp} \right) + 2J \left(W^S - M \right) \frac{dM}{dp} \right], \tag{13}$$

where V^S refers to the agent's utility in equilibrium, and $\frac{dF^S}{dW^S}$ represents the increase in food consumption required to maintain a higher stable weight value.[23] U_W refers to the marginal utility of an increase in the stable weight, which is the same as the marginal utility of an increase in final weight within a given period. The terms inside the first set of square brackets represent the welfare effects of the price change holding the norm fixed. The terms inside the second set of square brackets capture the additional impact on welfare prompted by the change in the equilibrium norm. Assume in an initial equilibrium that the consumer weighs more than the norm, in which case the marginal utility of weight gain, U_W, is negative and the marginal utility of food, U_F, is positive. Holding the norm fixed, a food price decline may or may not make the (myopic) consumer better off. Welfare will improve only if the benefits of added consumption (of both food and non-food goods) outweigh the costs of weight gain, where in a fixed health norm framework these costs can be interpreted as additional health risks.

Now consider the welfare effects prompted by the adjustment of the norm. The social multiplier effect set off by the price drop induces additional weight gain and food consumption, but less non-food consumption (to satisfy the budget constraint holding income constant–this need not imply lower non-food consumption on net when including price effects as well). Also, in the aggregate it leads to an increase in the value of the weight norm. Again the effect is ambiguous. The benefits are that she eats more and, ignoring the price effects on weight, her own weight moves closer to the norm. The latter result holds (for an initially overweight individual) because the increase in stable weight caused by the norm change is less than the increase in the norm, that is $\frac{\partial W^S}{\partial M} < 1$. The cost is that she gives up some non-food consumption.

Given the ambiguity in both components of the welfare change, the net welfare effects of a price

[23] In a linear metabolism model this number would be a constant that depends on the individual's shock; with quadratic metabolism this value still depends on the idiosyncratic shock, but it also decreases linearly in stable weight.

change are ambiguous, hinging on the relative marginal utilities and disutilities of weight gain, consumption, and deviation from the norm, and on the magnitude of changes in behavior and in the equilibrium norm. The indeterminacy applies to initially overweight as well as initially underweight individuals.[24] Also, because for a given price change welfare in a fixed-norm model may move in the opposite direction as in a moving-norm model, the consumers in our framework may prefer a world with flexible norms to a world with fixed norms. However, health-care professionals (and healthy individuals that subsidize the costs of treating obesity-related disorders) would likely prefer that people judged themselves against a fixed health standard.[25]

4 Experiments

The simulation exercises generate equilibrium weight distributions and norms under various specifications of the model, and compare the simulated distributions to the empirical evidence. We calibrate the model to women ages 30 to 60, setting an initial list of parameters to roughly match average weight for this group observed in the 1990 BRFSS data, and the food budget share estimated by Huang (1993). The goal is to assess the model's ability to predict higher moments of the distribution, most importantly to capture the growth in the upper tail of the distribution observed over the past twenty years. To do this we examine the shape of the simulated equilibrium weight distribution at three different price levels meant to roughly reproduce food price declines in the U.S. between 1976 and 2002. By comparing price effects in the endogenous norm model to an alternative with a fixed norm we also obtain an estimate of the social multiplier. To reveal the respective roles of genetic, social, and economic factors, we compare the price effects under different descriptions of metabolism, different specifications of the

[24] Simulated welfare effects are discussed in Section 3.2.3.

[25] Welfare effects in a model with forward-looking consumers, whether norms are fixed or flexible, are unambiguously positive. Philipson and Posner (1999) show this for the fixed norm case. Cutler et al. (2003) raise the possibility of welfare losses for individuals with imperfect self-control, but they estimate that the costs of weight gain have likely been less on average than the benefits of time savings in food preparation. This argument hinges on a calculation that the time saved in food preparation was more than enough time to burn the added calories consumed by the average American over the time period they measure (1965-1995).

target weight, and differing degrees of social complementarity. Despite some ambiguities the model does a good job replicating the recent trends in the weight distribution. In addition to rising average weights and rising obesity rates, the model captures the increases in 95th and 99th percentile.

In each experiment we draw 50000 values from the shock distribution; these values are held fixed across the experiments to prevent noise from clouding the effect of changes to the model. For a given set of parameters stable equilibrium weights always bear an inverse, one-to-one relationship to the metabolic shock. Low metabolism individuals eat less than those with higher metabolism, but not enough less to compensate and therefore weigh more in equilibrium. Two individuals with similar shocks, existing in communities targeting different norms or facing different prices, however, will have different weights in equilibrium. As such the model balances biological, social, and economic influences rather than being narrowly deterministic in any dimension. The results from the experiments are presented in a series of figures of simulated weight distributions following the text. To facilitate the comparison we provide a one-page summary of these distributions in Table .

4.1 Calibration of model

For the linear metabolism case we adopt Schofield's point estimates of the constant term and the coefficient on weight for women in the 30-60 year old group. Respectively these values are 844 and approximately 3.7, where units are kilocalories per day and weight is expressed in pounds. In the quadratic case we use the same coefficients on the linear terms but add the term $-.001W_i^2$. Recall that ε represents the idiosyncratic metabolic shock, which perturbs the coefficient on weight (but not on weight-squared) in the metabolism function. We assume the term is normally distributed with mean zero and standard deviation of 0.75. This value implies an average absolute deviation that is in line with the mean of the relevant (additive) Schofield residuals. The quadratic coefficient implies that metabolism for a 200 pound woman is 40 kcal less per day under the quadratic specification than under the linear model, implying a weight increase of 4.17 pounds annually holding caloric intake constant.

For a 120 pound woman the corresponding annual weight gain would be 1.5 pounds.

To calculate obesity rates we measure the percentage of people that weigh more than 174.5 pounds. For a woman of average height, approximately 64 inches in the U.S. for the relevant age group, this weight implies a body mass index of 30, which is the official obesity threshold established by the Centers for Disease Control. The marginal utility of the first unit of food in a week is identical across individuals and exceeds the marginal utility of the first unit of non-food consumption by 18%. Income and prices are chosen such that in the baseline equilibrium the average person is spending about 20% of her income on food purchases, which matches empirical measurements (Huang 1993). The price represents the price of 1 pound of body weight, or 3500 calories, which is about the amount burned in 1.5 days by a moderately active 140 pound woman. In nominal terms we experiment with this price at \$50, \$40, and \$32. Income was set at \$600 per week or \$31,200 per year.

The price in the model represents the full (or shadow) price of producing calories taking into account the consumer's costs of inputs to food production, including both raw inputs and time costs. As Figure 1 suggests there is evidence that the costs for key food inputs in meal production have fallen substantially relative to the basket of all consumer goods. The prices of ground beef, chicken, eggs and lettuce have grown 50 percentage points less than the price for the consumer basket since 1980. In addition, there is evidence that the time costs per meal have declined due to greater availability of restaurants (in particular fast food and take-out) and technological advances in food processing, storage, and food preparation. Cutler et al. (2003) show that the average amount of time spent on food preparation and cleanup declined from 53 to 31 minutes per day (42%) between 1975 and 1995 for 18-64 years old. While there is no definitive guide to weighting these different costs in the full price of food, the simulation exercises investigate the effects of a 36% decline in the full price per calorie since 1976-80, which seems quite plausible given the observed development of relevant input prices during that period.[26]

[26] As shown in Figure 2 the Bureau of Labor Statistics estimates that the relative price for typical food-away-from-home increased until 1978 but has declined by almost 6 percentage points since then. The relative costs of purchasing the typical food-at-home consumer basket are estimated to have declined by 15 percentage points between 1978 and 2002. However,

4.2 Linear vs. quadratic metabolism

As discussed above recent studies have found evidence that basal metabolism per unit of body weight is substantially lower for obese individuals than for non-obese people. While a weight-linear model provides a good fit for the non-overweight population, it overestimates basal metabolism for individuals in the upper tail (Horgan and Stubbs 2003). This fact is not just a consequence of selection. While individuals that inherit a low metabolism shock are more likely to wind up overweight, and this is true in our model, basal metabolism per pound per day is further depressed as a given individual gains weight in the form of excess body fat. This is true even for non-overweight individuals that experience changes in body composition without becoming overweight (see Pullicino et al. 1996, and Horgan and Stubbs 2003). Previous economic analyses of obesity have adopted the linear model of metabolism, and ignored idiosyncratic variation. While such models can generate results for a "typical" individual, they cannot make reliable predictions across the population, and will miss important dynamics that arise as the weight distribution moves to the right. Cutler et al. posit variation in preferences to get variation in outcomes, for example invoking variation in self-control to explain growth in the upper tail of the weight distribution. Without an explicit model of heterogeneity, however, this prediction seems vague and ad hoc. Although they do not derive the population-level implications of the linear metabolism model, we find that the linear model fails to capture important features of the empirical weight distribution. This finding supports the biological evidence that the linear model is not appropriate for heavier individuals.

To draw out these results we examine the effect of decreasing food prices within both the linear and quadratic specifications of metabolism, holding all other parameters fixed. By assumption the reference

the overall food CPI is not a reliable measure of the price per calorie of food, and the index is likely to have substantially underestimated the decline in the price per calorie over the period of interest. This is due to the changes in the CPI weights on individual food items and changes in the list of included items to reflect actual consumer expenditure patterns (see BLS Handbook of Methods, http://www.bls.gov/opub/hom/pdf/homch17.pdf). Consumption data show that the share of calories coming from fats in the typical American diet has increased from 17.7% to 21.4% between 1970 and 2000. Since fat has more calories per gram of food, even a diet involving the same number of grams of food will now contain more calories. If the CPI weights capture this trend the total calories in the basket must have increased. In addition since the CPI basket reflects actual expenditures its energy content may also have increased due to growth in portion sizes. USDA consumption data show that per capita calorie consumption (adjusted for losses) has increased by about 22% since 1975 (see Putnam et al. 2002). In addition, as argued before, falling time costs are not accounted for in the CPI data.

weight is defined as 88% of the realized average weight in equilibrium, consistent with the findings from the BRFSS for women discussed above. In both models the weight distribution is asymmetric in equilibrium as a result of the heteroscedastic shocks.[27] However, for the linear case the 95th (99th) percentile of the distribution increases by 21 (24) pounds as the price falls while in the quadratic case the 95th (99th) percentile is greater at each price level than in the linear model, and increases by 24 (30) pounds as price falls from $50 to $32. For more details see Figures 7 and 8. According to the NHANES the 95th (99th) percentile of the female weight distribution (ages 30 to 60) increased by 36 (47) pounds between 1980 and 2000.[28]

The quadratic model's predictions under the $40 price match the 1988-1994 NHANES III data quite well. For example the model predicts an average weight of 157.6 pounds, a standard deviation of 31.3, a 95th (99th) percentile weight of 214 (260) pounds, an implied obesity rate of 23.1%, and a skewness value of 1.716. The corresponding NHANES III values for 30-60 year old women are 157.4 (mean weight), 39.5 (standard deviation), 23.8% obesity rate, 231 (290) pounds (95th (99th) percentile weight), and 1.207 (skewness). See Figure 8) for more detail. The parameters were selected only to approximate the average weight value of 157 pounds at this price; the remaining statistics were not computed in making adjustments to the calibration. The quadratic simulations capture most of the qualitative changes in the NHANES data before and after 1988-1994, where the $50 price is meant to represent 1976-1980 and $32 represents 1999-2000. In terms of quantitative comparisons, if the real "full" price of food fell by 20% over the 1988 – 1994 to 1999 – 2002 period, the quadratic model slightly underestimates the magnitude of the price effects on mean weight, 95th (99th) percentile weight, and the standard deviation. However, the linear model predicts even smaller values for the standard deviation, both in levels and price effects, as well as smaller increases in 95th (99th) percentile weight.

[27] When the shocks are homoscedastic the equilibrium distributions are symmetric.

[28] Over the same twenty year period 95th (99th) percentile weight also increased steadily for men. We discuss gender differences in Section 3.2.3 below.

4.3 Exogenous vs. endogenous norms

In contrast to our endogenous or evolving norm specification, other models that include a weight norm (Philipson and Posner 1999, Levy 2002) treat the norm as exogenous. While the exact basis for the norm is not specified in these models, the interpretation might be that desired weight is targeting an objectively optimal weight from the standpoint of health, or a genetically hard-wired aesthetic standard. Alternatively norms may adjust with a lag, such that the exogenous case captures the short run. A comparison of outcomes between these specifications may offer a basis on which to test their relative validity, in addition to yielding an estimate of the relative effect of prices and the social multiplier. The fixed norm case simply holds M constant at some arbitrary level; individual optimization conditions do not change, but the norm-consistency condition is no longer relevant. Any given value of M results in a unique distribution of stable weights regardless of whether the norm bears the right relationship to population weights.

Adopting the quadratic model of metabolism and employing the same sets of metabolic shocks across the cases (and the same as in the experiments above), we compare the effect of price declines between the fixed and moving norm models. The results for the fixed norm experiment are presented in Figure 9. In the exogenous model, we set the norm equal to its equilibrium value in the endogenous model for the price of $50 (see Figure 8). Therefore when price is $50 the distributions are identical in both models. As the price falls to $40 and the norm is held fixed (in each run at a value close to 130 pounds) the changes represent the partial effects of price on the equilibrium weights. For this price drop, all the statistics of interest increase: the mean, standard deviation, skewness, 95th percentile weight, 99th percentile weight, and the obesity rate. As expected the increases are consistently smaller than when the norm adjusts, and the models get farther apart as price falls further. See Figures 8 and 9 for specifics.

This comparison provides an estimate of the social multiplier effect, both in absolute terms and in relation to the partial price effects. Recall from above that our social multiplier represents the (adjusted) average of the partial effects of the norm on weight, that is

$$m = \frac{\zeta}{N} \sum_i \frac{\partial W_i^S}{\partial M}. \tag{14}$$

Our estimate of this value measures the ratio of the average rate of change in average weight (multiplied by .88) to the average rate of change in the equilibrium norm over a given ten-dollar price interval. For a price drop from \$50 to \$40 the estimated social multiplier is .189. This value implies that the rate of change in average weight caused by a price change will be 1.23 times its magnitude in the fixed-norm case. If the weight norm adjusts with a lag, the price elasticity of body weight should be greater in the long-run than in the short-run. In contrast a standard rational choice model, with no sticky eating habits and fixed or nonexistent weight norms, should not expect a significant time-horizon effect on this price elasticity. The challenge in testing this prediction will lie in deriving independent estimates of the length of the short-run, and in isolating the long-run effect of a one-time price change from the effects of subsequent price changes.

We also track the welfare effects of the price changes in the contexts of the fixed and moving norm models. With an endogenous norm, we find that the initial price change, from \$50 to \$40, leaves most individuals, 80% of the population, marginally better off. The greatest welfare gains accrue to those closest to the initial weight standard. Gains decline with initial differences between weight and the norm, eventually becoming negative. Welfare gains (losses) are not symmetric in the metabolic shock, however, given the concavity of the metabolic function, and very low metabolism individuals suffer the greatest losses. When price declines from \$40 to \$32 the changes are very similar, and 79% of the population is made better off. If norms are held fixed, however, the initial price change improves welfare for only about 47% of the population, specifically those in the upper half of the metabolic distribution. Welfare gains (declines) are slightly smaller (greater) for the second price decline, and only 37% of the population is made better off. Therefore a substantial portion of the population fares better in a society with flexible norms than in one with rigid standards, where welfare is evaluated on a subjective and relative scale.

4.4 Effect of variation in the reference weight model across groups

So far we have defined the equilibrium reference weight as 12% below the mean population weight, based on the desired-weight data for women. However, desired weights for men are closer to 5% below average male weight. We also find significant differences, by race but within gender, in the relationship between mean desired weight and mean actual weight. These findings suggest that weight norms are gender and race specific, and that we might expect systematic differences in weight distributions across groups as a result. To elicit such differences we derive the effect of variation in the norm target on the weight distribution. Taking the same 50000 shocks, we set the norm at 15% below mean weight in one experiment, and at 5% below in another, under the quadratic metabolism model. For the baseline price of $40, the "low target" group arrives at an equilibrium norm of 132.9 pounds, with a realized mean weight of 156.4 as shown in Figure 10. Predictably these values are lower than those for the high target group, in which the norm was 152.6 and the average 160.6 as shown in Figure 11.

While the average weights are just four pounds apart, the low norm group has a less skew distribution. Skewness again varies inversely with price, and the price effect on skewness is greater for the group targeting the high norm. The comparison is relevant to male-female differences because desired weights for men are on average only 5% below average actual weights. This difference is consistent with findings of greater body dissatisfaction among women than men (Mintz and Betz 1986). While other things are clearly not held constant in a comparison of men and women, we do see the predicted qualitative differences in the distributional trends by gender in the NHANES and BRFSS surveys.[29] For example the standard deviation and the skewness of the weight distribution was lower for men than women (contrary to the model's prediction), and both increased over the time period for men while the skewness declined somewhat for women (see Figure 5 and 6). However, we cannot at this point guar-

[29] The fact that male desired weights track closer to the mean is not a consequence of the fact that men's actual weights are closer to medical ideals to begin with. Mean BMI for men is only half a point below that for women.

antee that the predicted differences are robust to a rescaling of the model to match male metabolism.

While the relationship between media-promulgated body ideals and actual desired weights is complex and uncertain, it is possible that the popular imagery has caused a reduction in the target weights as a proportion of the mean, if not in absolute terms. We observed above from the BRFSS data that average desired weight for 30-60 year old women, as a fraction of actual average weight, fell from .877 to .865 over the period from 1994 to 2000 (.943 vs. .933 for men). If popular imagery tends to exalt what is scarce or unattainable rather than what is realistic, the fact that models and celebrities have gotten thinner as the rest of us have gained weight makes cultural sense, and need not contradict the assertion that the de facto norms to which individuals aspire move up with actual weight.

4.5 Variation in the strength of social interactions

We now consider how variation in the coefficient J, which affects the cost of deviation from the reference weight, affects equilibrium outcomes. Again we define the norm as 12% below average weight. Not surprisingly a higher value of J, which represents stronger social influence, reduces the variance of weights within a group, and reduces the skewness of the distribution. In a simulation setting J at .01, the equilibrium norms, means, standard deviations, skewness, and 95th and 99th percentile weights are all lower (in the quadratic model) for each value of price than in the previous simulations with J at .002. In addition, the price effects on equilibrium outcomes are smaller for the larger value of J (compare Figures 8 and 12). In this case stronger social interactions reduce the sensitivity of weight to price, ceteris paribus, and reduce the net effect of price on equilibrium weights, despite the presence of a larger social multiplier. In general, however, as discussed in the context of the comparative statics, the effect of J on price effects is ambiguous.

Our example illustrates a case in which strong social influence may be seen as restraining the growth of obesity in response to falling food prices. Such an outcome would confer physical health benefits on some, but also would impose higher costs on non-conformists. Regardless of the net welfare effect, the analysis raises the question of what determines the strength of social influences on body weight. Sociological research has found that age and gender, among other factors, play a role, and young white women have been identified as a group that feels strong pressure to conform to weight norms (Dwyer et al. 1970, Ross 1994). In a companion paper (Burke and Heiland 2005) we advance the hypothesis that more educated women face a higher deviation cost than less-educated women, on the basis of wage penalties and delayed childbearing. The model captures important qualitative differences in female weight distributions in the U.S. by education class, and suggests possibilities for further research concerning differences by race, ethnicity, and nationality.

5 Conclusion

This paper presents a new framework for relating the increase in obesity rates to falling food prices. Relative to earlier models also emphasizing the role of prices, we predict larger effects of price declines on weight, due to the social multiplier effect. This effect occurs because, as prices fall and weights rise, the reference weight to which individuals aspire also increases, and weights adjust upward further in response. This latter response implies an outward shift of the food demand curve, and an offset to the original price decline in the eventual equilibrium. Under this effect an increase in food supply leads to an increase in demand. If norms adjust with some lag the model predicts that the price elasticity of body weight and food consumption should be greater in the long run than in the short run. With myopic behavior and moving norms a decline in the price of food may leave individuals worse off.

In addition to general increases in weights, our model explains the large increases in the size of the upper tail of the weight distribution. This prediction relies in part on another important innovation of our framework: the explicit representation of metabolic heterogeneity. This model enables description of a complete distribution of weights. As prices and food intake change, the changes in metabolism as a function of weight interact with endogenous changes in the weight norm to produce changes in the shape of the equilibrium weight distribution that mirror recent empirical trends. While other models have predicted qualitative increases in obesity rates, in doing so they have relied on variation in preferences, and have not precisely linked the individual heterogeneity to descriptions of complete weight distributions at different prices.

In future extensions of this research we hope to incorporate even greater complexity in the model of metabolism. Research shows that in addition to metabolic changes with body weight and composition, metabolism may exhibit path dependencies. For example chronic dieters may experience a reduction in metabolism, and the body may resist attempts to alter weight from a long-established value (Labayen et al. 2004). These dynamic effects emphasize the potential irreversibility of weight gain, and stress the importance of prevention for individuals wishing to avoid permanent overweight or obesity. As our model shows, however, unless individuals take such long-run dynamics into account they are unlikely to avoid such traps as food becomes cheap and plentiful. Furthermore the implicit social pressure to maintain a healthy weight declines as increasing numbers of people become overweight, regardless of increasingly stern health warnings from doctors and public officials.

In the model as it stands there is nothing to restrain the weight norm, and therefore population weights and obesity, from continuing to rise as prices continue to fall. In fact at existing prices the social multiplier effects may not yet be fully played out. While the price elasticities of food and weight are lower beginning from lower prices, the model predicts no qualitative reversal of the current trends. Lakdawalla and Philipson (2002) have hypothesized that obesity growth could be self-limiting, based on a projection that future income growth will lead to lower average weights. Given the increasingly weak relationship between income and obesity rates, and the uncertain prospects for broad-based income growth, the prediction is highly tenuous.

Within the context of our model, there may be justification for a tax on food. While we do not describe food quality in this context, low-nutrient and calorically dense foods would be the likeliest targets. While food taxes may be politically infeasible, public education aimed at influencing weight norms is an alternative strategy that is already in play. In the past twenty years such efforts have focused primarily on the promotion of official dietary guidelines such as the Food Guide Pyramid.

These campaigns have clearly failed to restrain caloric intake, in light of observed weight and food consumption trends over the same period. A telling fact about American consumers is that the number of people who reported that they were eating “pretty much whatever they want” reached an all-time high in 2002 (Putnam et al. 2002). Some state governments have taken a more aggressive stance in recent years, in light of increasing evidence on the health effects of obesity. For example during the 2001 academic year, full time public schools in Florida conducted a mandatory health screening. Elementary and high school students had their height and weight measured by the school nurse. Schools classified students as normal, overweight, or obese and reported results to parents. We see this as an attempt to promote or reinstate a health-based weight norm, possibly countering the social dynamics that lead to higher weight standards. If such campaigns succeed in helping children, and perhaps their parents, to maintain healthy weights, they will be welfare-enhancing. However if the programs result mainly in heightening the negative social perception of overweight rather than changing behavior, the net effects may be detrimental. As in the public campaign against smoking, we anticipate a growing controversy over public efforts to impose value judgements on individuals.

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Mathematical Appendix

In this appendix we provide brief verifications of the assertions of the existence and convergence statements of individual stable weight laid out in Section 3.

The optimal one-period choice of food and non-food consumption, beginning from any initial weight value, must satisfy equations (5), (8), and (9), as well as second order conditions. The three equations can be combined and rewritten as the following optimality condition on end-of-period weight, W_t, for any initial weight W_{t-1}.

$$U_F(F(W_t^*|W_{t-1}))\frac{dF}{dW} - pU_C(C(W_t^*|W_{t-1}))\frac{dF}{dW} = 2J(W_t^* - M). \tag{15}$$

The left-hand side of equation (15) represents the marginal effect on one-period utility of end-of-period weight, deriving from the changes in food and non-food intakes consistent with a marginal change in the final weight. The right-hand side represents the marginal effect of end-of-period weight on the cost of deviating from the norm. The partial derivative U_F is evaluated at the food level consistent with the beginning and ending weights, where this food level is denoted $F(W_t|W_{t-1})$. The partial derivative U_C is evaluated similarly. The expression $\kappa := \frac{dF}{dW} > 0$ represents the increase in food consumption needed to achieve a marginal weight gain, holding basal metabolism fixed. This is an identical constant for all individuals, representing the conversion rate of calories into body weight, netting out the calories consumed in digestion. Values for the left-hand side of (15) depend on both the initial weight and the final weight, but values for the right-hand side depend only on the final weight.

Existence of a stable weight

A stable weight must satisfy the equation above as well as the condition that $W_t^* = W_{t-1}$. To check for existence of such a weight, impose the condition that $W_t = W_{t-1}$ and determine whether (15) has a solution. Consider the values $[U_F(F(W|W)) - pU_C(C(W|W))]\kappa$. The expression gives the net marginal benefit of weight gain beginning from any weight W, where each W is potentially an initial weight value at some point in time. If starting from some initial weight the net marginal benefit of weight gain happens to be equal to the marginal cost of weight gain, it is optimal to exactly maintain the initial weight. Since any stable weight must satisfy this property, the locus of these net marginal benefits will be termed the "sustainability locus," and it will determine stable weight for any M. Values on the locus are initially positive, given the high marginal utility of food at the food intake consistent with just maintaining a very low weight, and the low marginal utility of non-food consumption. The function decreases in weight, eventually becoming negative. This decline occurs because metabolism increases in weight, and therefore the food required to maintain weight is increasing; as required food intake increases, the marginal utility of food decreases, and the marginal utility of non-food consumption increases. The right hand side is initially negative (assuming M is greater than some minimal viable adult weight), but becomes positive as weight gets above M. Thus there is a unique weight, $W^S(M)$, characterized by

$$[U_F(F(W^S|W^S)) - pU_C(C(W^S|W^S))]\kappa = 2J(W^S - M). \tag{16}$$

Convergence to a stable weight

To show convergence to this stable weight consider one-period optimization from any initial weight, W_0, as illustrated in Figure 13. Consider the marginal net benefit of end-of-period weight as seen in the diagram. Values on this curve are again initially positive, and become negative as final weight, W_1, increases. This marginal benefit curve, however, has a steeper negative slope than the sustainability locus. This is because, as weight increases from W_0 to some W_1, the marginal net benefit of further weight gain evaluates U_F at $F(W_1|W_0)$, whereas the locus evaluates U_F at $F(W_1|W_1)$. Since the former food quantity is greater than the latter, the net marginal benefit of food (and of weight gain) is less than the value on the sustainability locus at W_1. The difference in these food levels arises because metabolism, measured in pounds of weight burned per week, grows less than proportionally to weight itself. For the same M the marginal deviation cost behaves exactly as above. Thus for any given initial weight there is a unique intersection point that determines $W_1^*(W_0)$. Second-order conditions are satisfied at this value given the strict concavity of the optimization problem in F and C. If W_0 lies below the stable weight defined by (16), the analysis in the previous paragraph implies that, beginning at W_0 a final weight of W_0 cannot be optimal. At this point the marginal benefit of weight gain exceeds the marginal cost, and so it is optimal to gain weight. However, the optimal weight gain is less than the difference between W_0 and the stable weight. This also follows from the fact that the marginal benefit of within-period weight gain declines more rapidly than the values on the sustainability locus. The diagram depicts the relationship between these two curves, indicating that $W_1^* < W^S$.

Referring to Figure 13, beginning from weight W_0 let the optimal ending weight be W_1, where the latter satisfies $[U_F(F(W_1|W_0)) - pU_C(C(W_1|W_0))]\kappa = 2J(W_1 - M)$. To iterate, let the individual begin at W_1 and again solve the one-period problem. Now the individual evaluates the marginal benefit of weight gain relative to this new initial weight. For the first increment this is just the value on the sustainability locus at W_1. Thus we have a new within-period net marginal benefit curve intersecting the sustainability locus at this point, where the new curve therefore lies to the right of that for the previous (lower) initial weight. Therefore when the individual wakes up at weight W_1, the marginal benefit of weight gain once again exceeds the marginal cost, and additional weight gain is optimal within the new period. However, since W_1 is greater than W_0, the marginal benefit of weight gain beginning from W_1 is less than that beginning from W_0, and the marginal cost is higher, implying a smaller optimal weight gain from W_1 to W_2, as seen in the diagram. Again the individual winds up below the stable weight. The same logic applies at the next iteration, during which the individual again gains weight but gains less than in the previous period. Weight gain occurs as long as $W < W^S$, yet converges to zero and ceases when W reaches the stable value. Had the initial weight been greater than the stable weight value, it can be shown similarly that the individual would optimally lose weight period by period until converging to the stable weight. Convergence occurs in finite time in simulations using Mathematica.

Existence of and convergence to a stable weight norm

The graphical analysis in Figure 14 indicates the condition on a stable weight for a given M. We can identify the stable weight for any M by plotting $[U_F(F(W|W)) - pU_C(C(W|W))]\kappa$ and $2J(W-M)$ and finding the value of W at their intersections. If M increases, the latter curve shifts right, and stable weight increases. This increase is less than the increase in M, however, because of the negative slope on the sustainability locus. For a more general functional form this is equivalent to imposing the "moderate social influence" (MSI) condition on the optimization problem. The MSI condition also guarantees existence of an equilibrium M (see e.g., Glaeser and Scheinkman 2002). The value of dW^S/dM approaches 1 as J approaches infinity. Simulations confirm uniform convergence.

Table 1: Summary of Weight Distributions

Distribution	**Mean (SD)**	**Min**	**Max**	**Median**	**95th**[a]	**99th**[b]	**Skewness**[c]	**Norm**[d]
Empirical Distribution (Figs. (5)-(6))								
Women 30-60, NHANESII, 1976-1980	148.4 (34.0)	80	360	141	215	258	1.356	N.A.
Women 30-60, NHANESIII, 1988-1994	157.4 (39.5)	77	470	150	231	290	1.207	N.A.
Women 30-60, NHANES99, 1999-2000	168.4 (45.6)	84	420	160	251	305	1.178	N.A.
Women 30-60, BRFSS, 1990	148.4 (31.6)	73	434	143	205	256	1.429	N.A.
Women 30-60, BRFSS, 2002	161.0 (38.6)	56	603	153	236	288	1.425	N.A.
Men 30-60, NHANESII, 1976-1980	177.3 (29.8)	100	350	174	230	264	0.615	N.A.
Men 30-60, NHANESIII, 1988-1994	185.4 (37.7)	90	532	180	251	317	1.476	N.A.
Men 30-60, NHANES99, 1999-2000	191.9 (43.4)	94	425	184	277	338	1.183	N.A.
Men 30-60, BRFSS, 1990	182.6 (31.7)	69	433	179	241	283	1.017	N.A.
Men 30-60, BRFSS, 2002	194.5 (39.7)	49	629	189	267	325	1.289	N.A.
Simulated Distribution (Figs. (7)-(12))								
Moving Norm (Linear, P=$50)	140.9 (25.3)	83	350	137	187	220	1.256	124.0
Moving Norm (Linear, P=$40)	150.0 (26.8)	88	371	146	199	234	1.253	132.0
Moving Norm (Linear, P=$32)	156.7 (28.0)	92	387	152	208	244	1.250	137.9
Moving Norm (Quadratic, P=$50)	147.5 (29.4)	84	484	142	201	243	1.675	129.8
Moving Norm (Quadratic, P=$40)	157.6 (31.3)	90	532	152	214	260	1.716	138.7
Moving Norm (Quadratic, P=$32)	165.1 (33.3)	94	572	159	225	273	1.751	145.3
Fixed Norm (Quadratic, P=$50)	147.5 (29.4)	84	484	142	201	243	1.675	129.8
Fixed Norm (Quadratic, P=$40)	155.7 (31.2)	89	522	150	212	257	1.705	129.8
Fixed Norm (Quadratic, P=$32)	161.7 (32.5)	92	552	156	220	267	1.730	129.8
Low Norm Group (Quadratic, P=$50)	146.3 (29.1)	84	478	141	199	241	1.669	124.4
Low Norm Group (Quadratic, P=$40)	156.4 (31.3)	89	526	151	213	258	1.709	132.9
Low Norm Group (Quadratic, P=$32)	163.7 (32.9)	93	565	158	223	270	1.743	139.1
High Norm Group (Quadratic, P=$50)	150.2 (30.0)	86	498	145	204	247	1.690	142.7
High Norm Group (Quadratic, P=$40)	160.6 (32.3)	92	550	155	219	265	1.733	152.6
High Norm Group (Quadratic, P=$32)	168.2 (34.0)	96	593	162	229	278	1.772	159.8
Strong Interactions (Quadratic, P=$50)	128.8 (12.7)	92	199	128	151	164	0.614	113.3
Strong Interactions (Quadratic, P=$40)	137.3 (13.4)	99	212	136	161	175	0.618	120.8
Strong Interactions (Quadratic, P=$32)	143.5 (14.0)	103	221	142	169	182	0.622	126.3

Note: [a]95th Percentile. [b]99th Percentile. [c]Skewness:$= \frac{\sum_i \left[(X_i-\mu)^3\right]}{(N-1)\sigma^3}$ for univariate data $X_1, X_2, \ldots, X_N$ where μ and σ denote mean and standard deviation. [d]Population Weight Norm, see discussion on experiments for details.

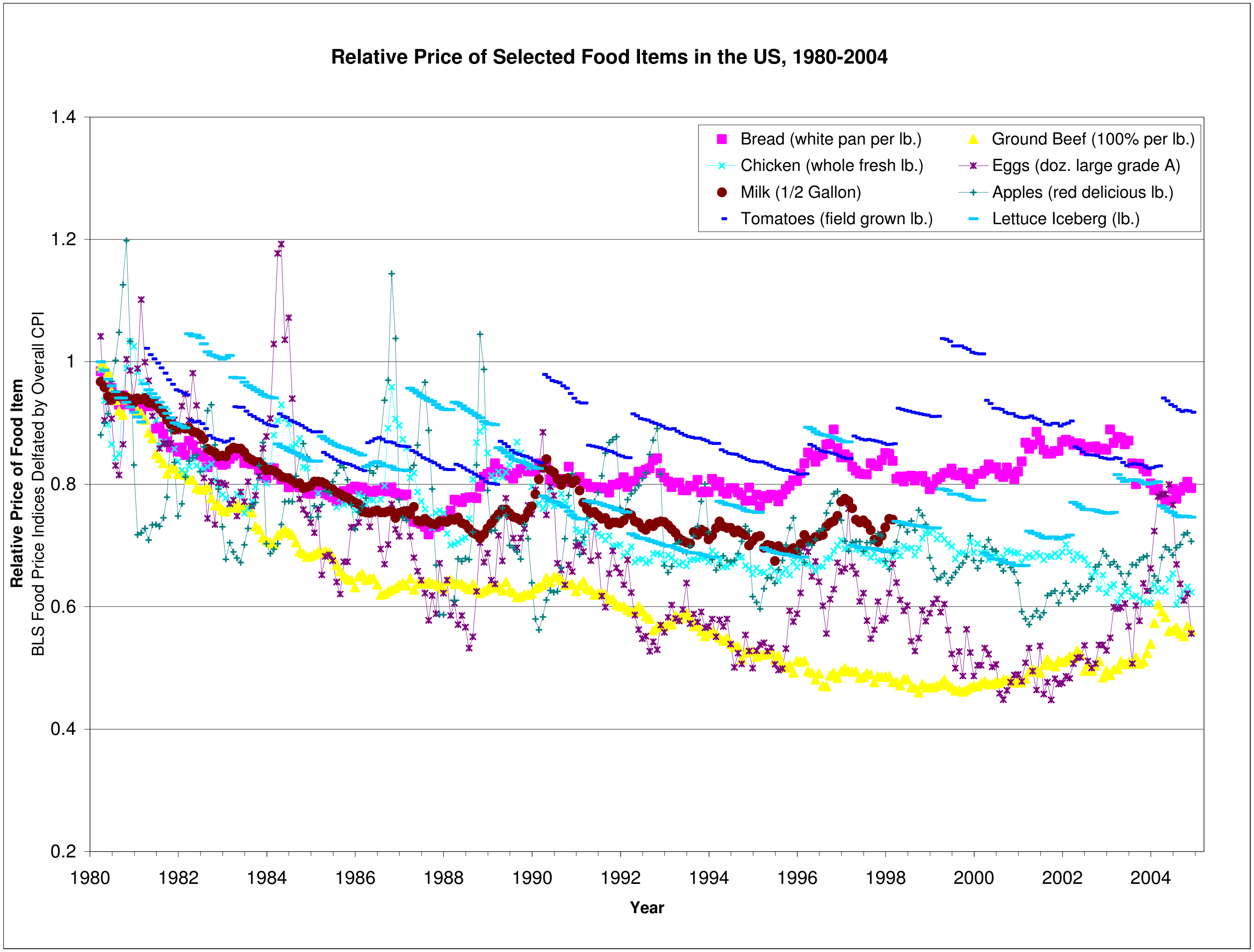

Figure 1: Relative Prices of Selected Consumer Food Items (1980=100%; Source: Bureau of Labor Statistics)

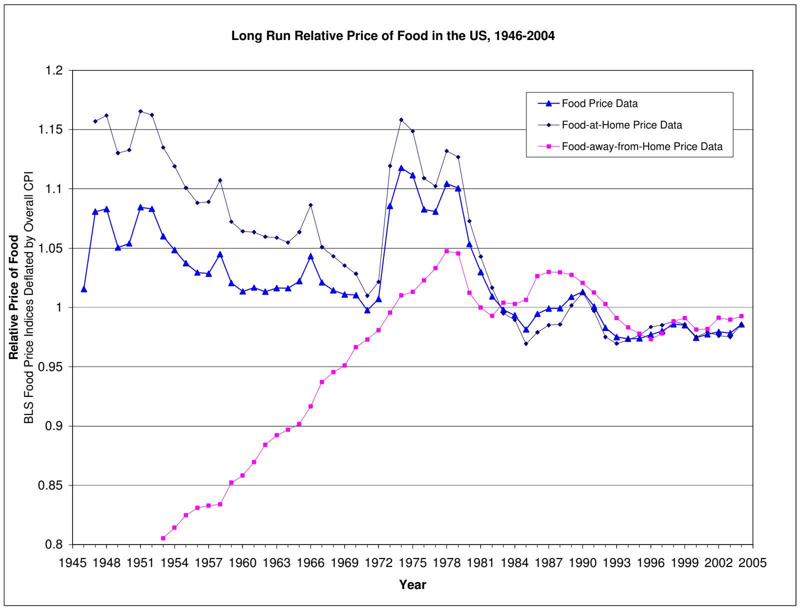

Figure 2: Long Run Trend in Relative Consumer Food Prices (1982-84=100%; Source: Bureau of Labor Statistics)

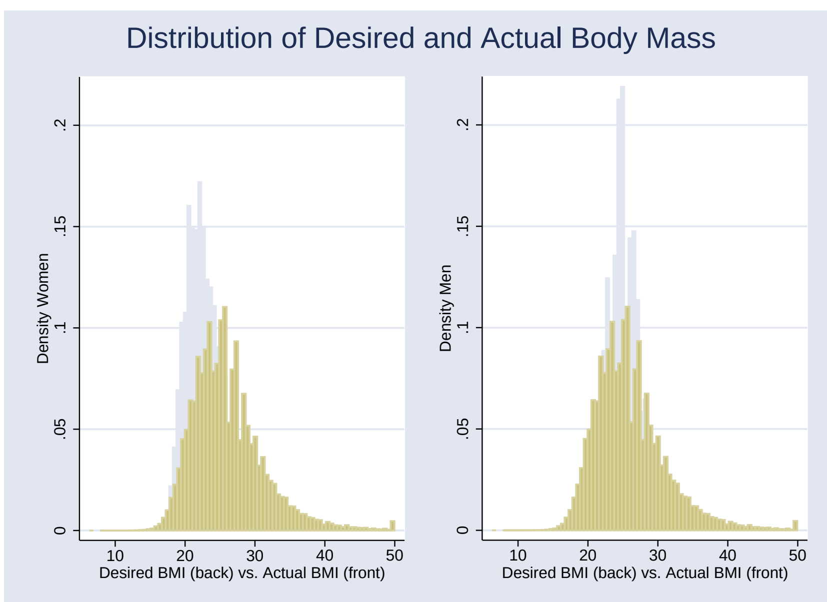

Figure 3: Actual and Desired BMI by Gender (Source: BRFSS various years; BMI>50 set to 50)

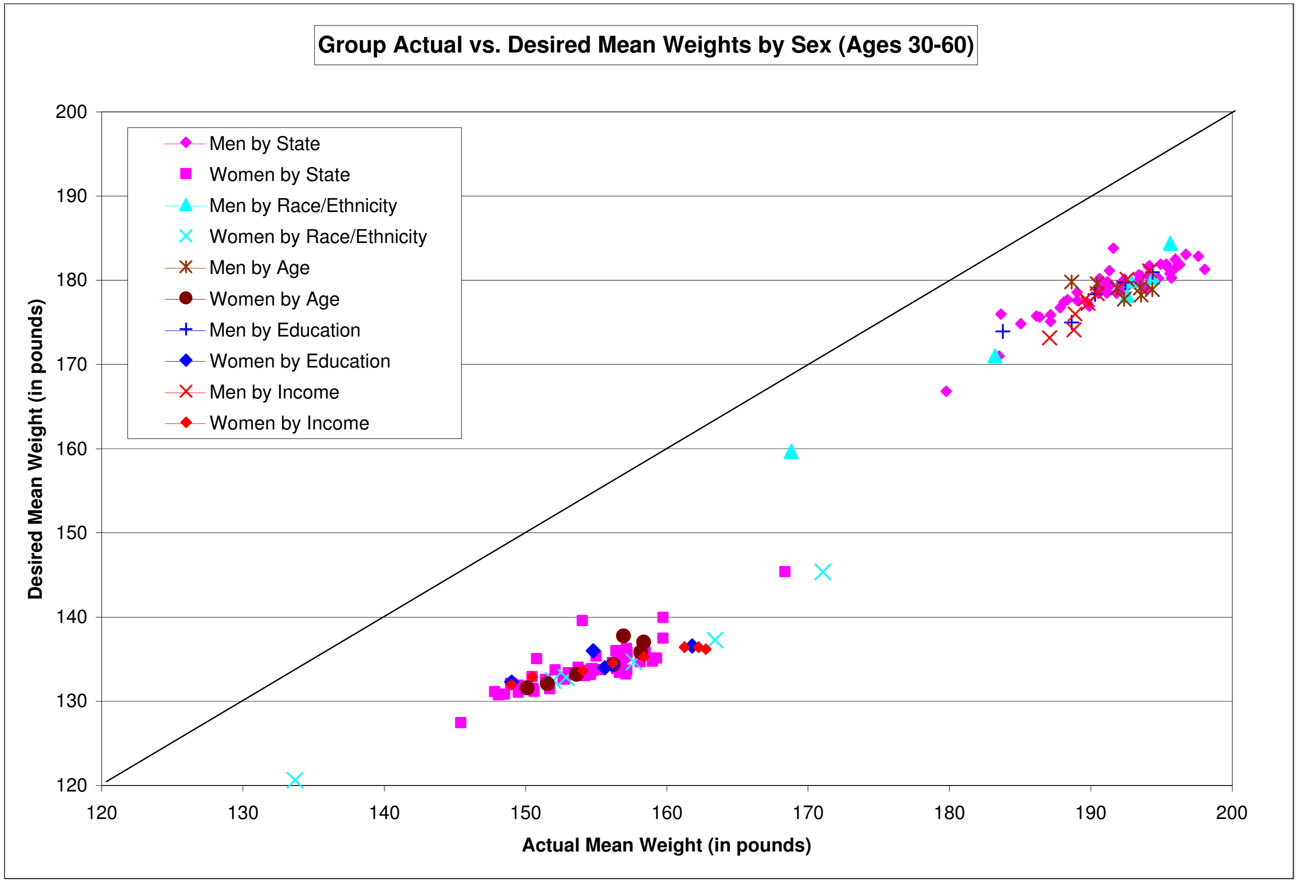

Figure 4: Relationship between Desired and Actual Weight by Groups (Source: BRFSS various years)

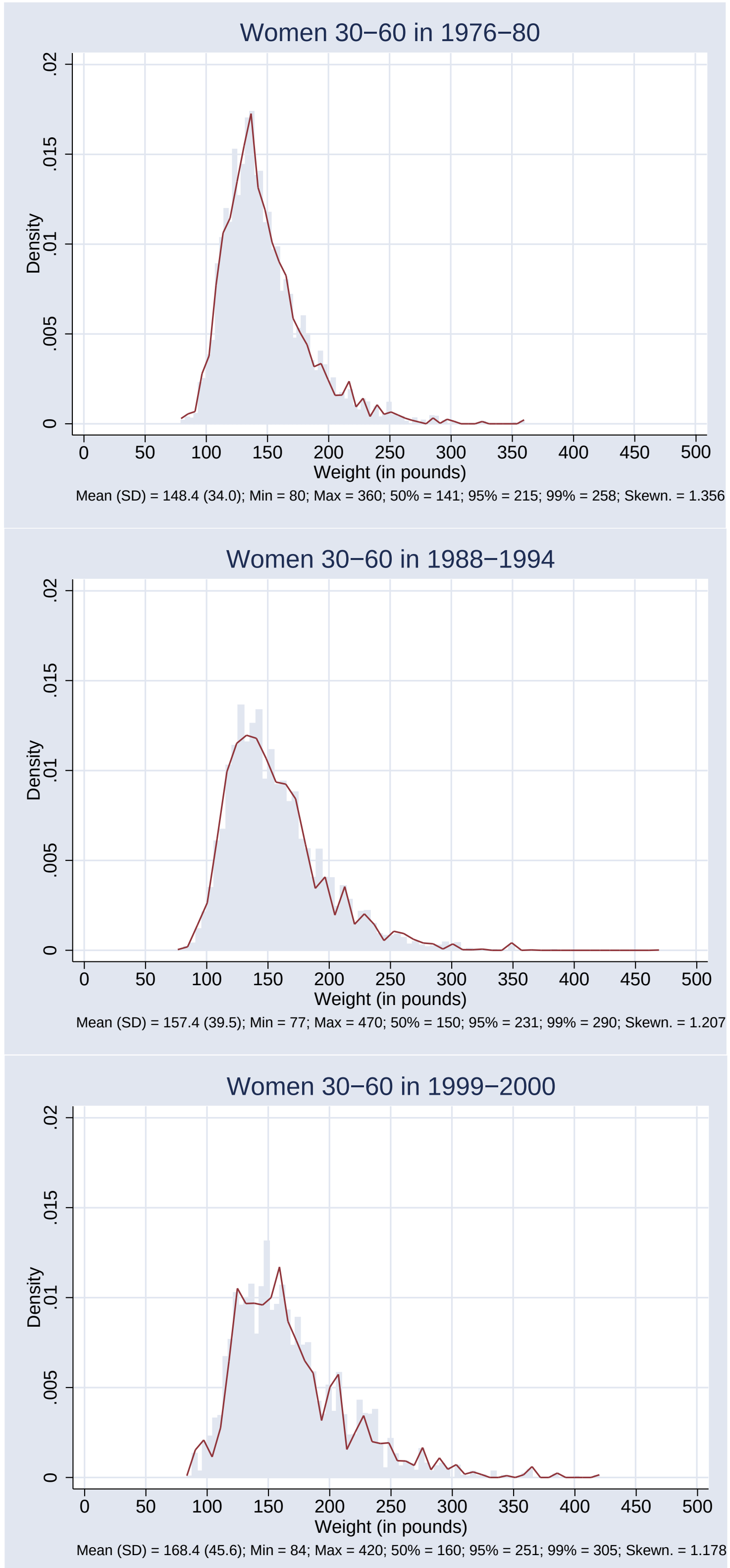

Figure 5: Female Weight Distribution 1976-1980, 1988-1994, and 1999-2000 (Source: NHANES II, III, and 99)

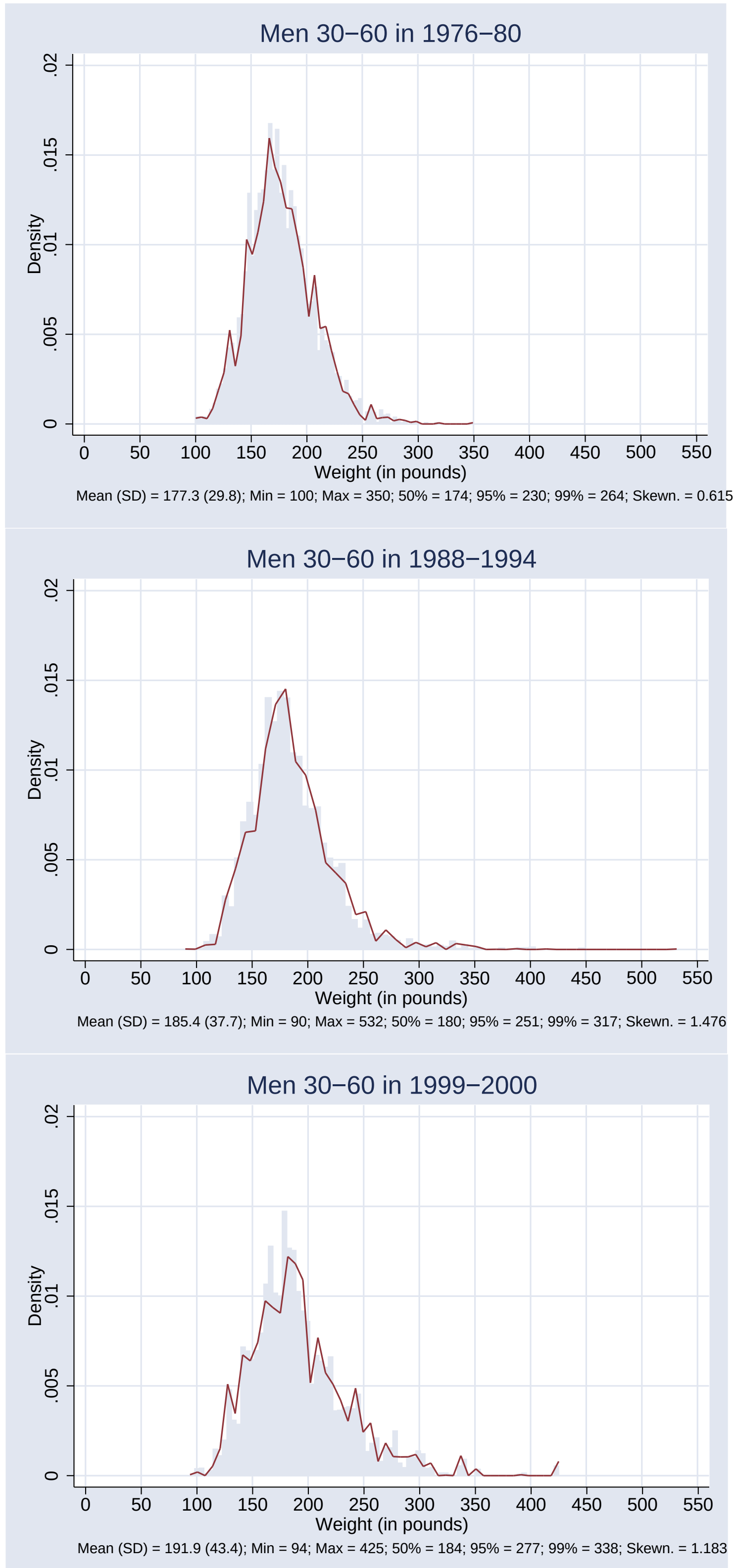

Figure 6: Male Weight Distribution 1976-1980, 1988-1994, and 1999-2000 (Source: NHANES II, III, and 99)

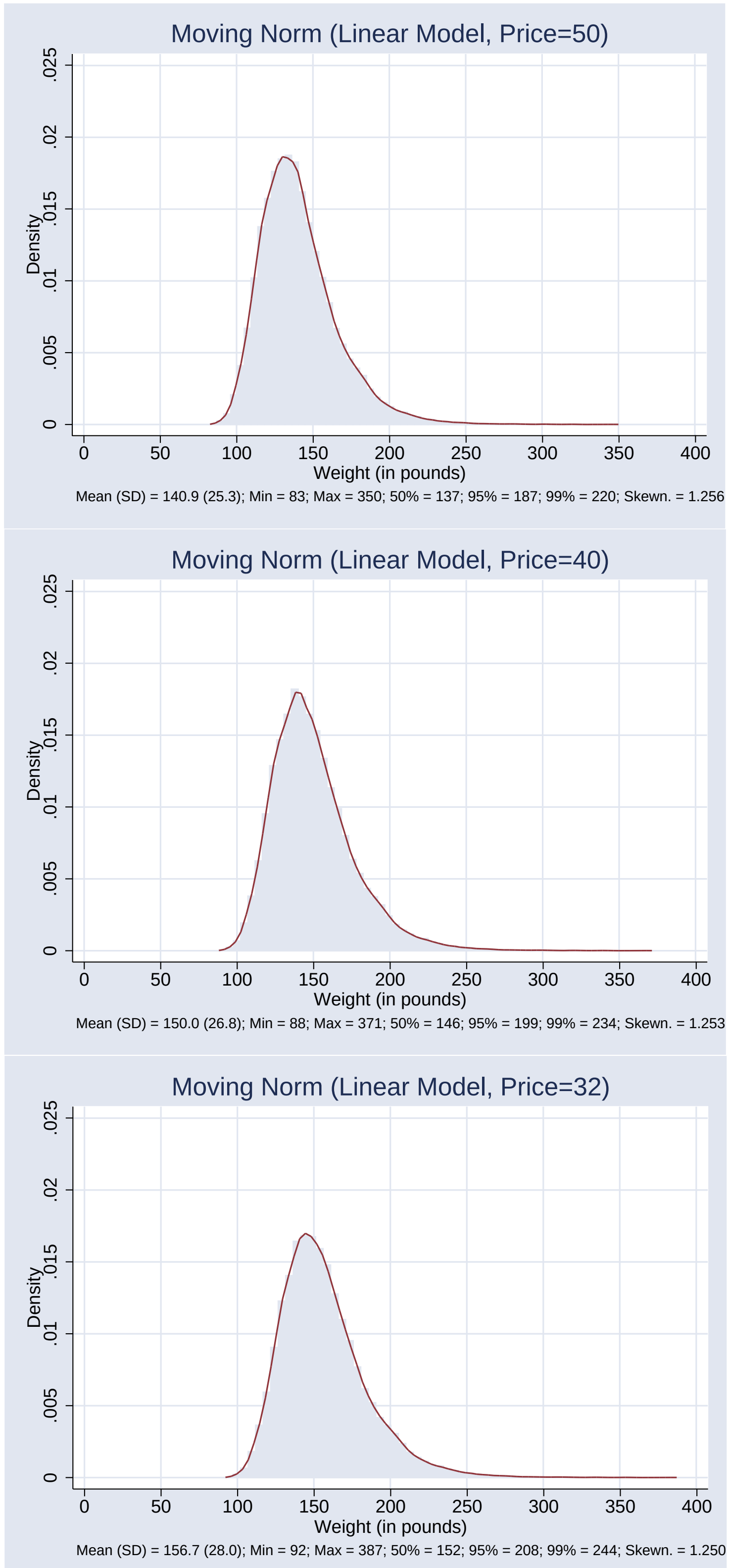

Figure 7: Single Group Price Experiment: Moving Norm, Linear Metabolism (with Kernel density estimate plot)

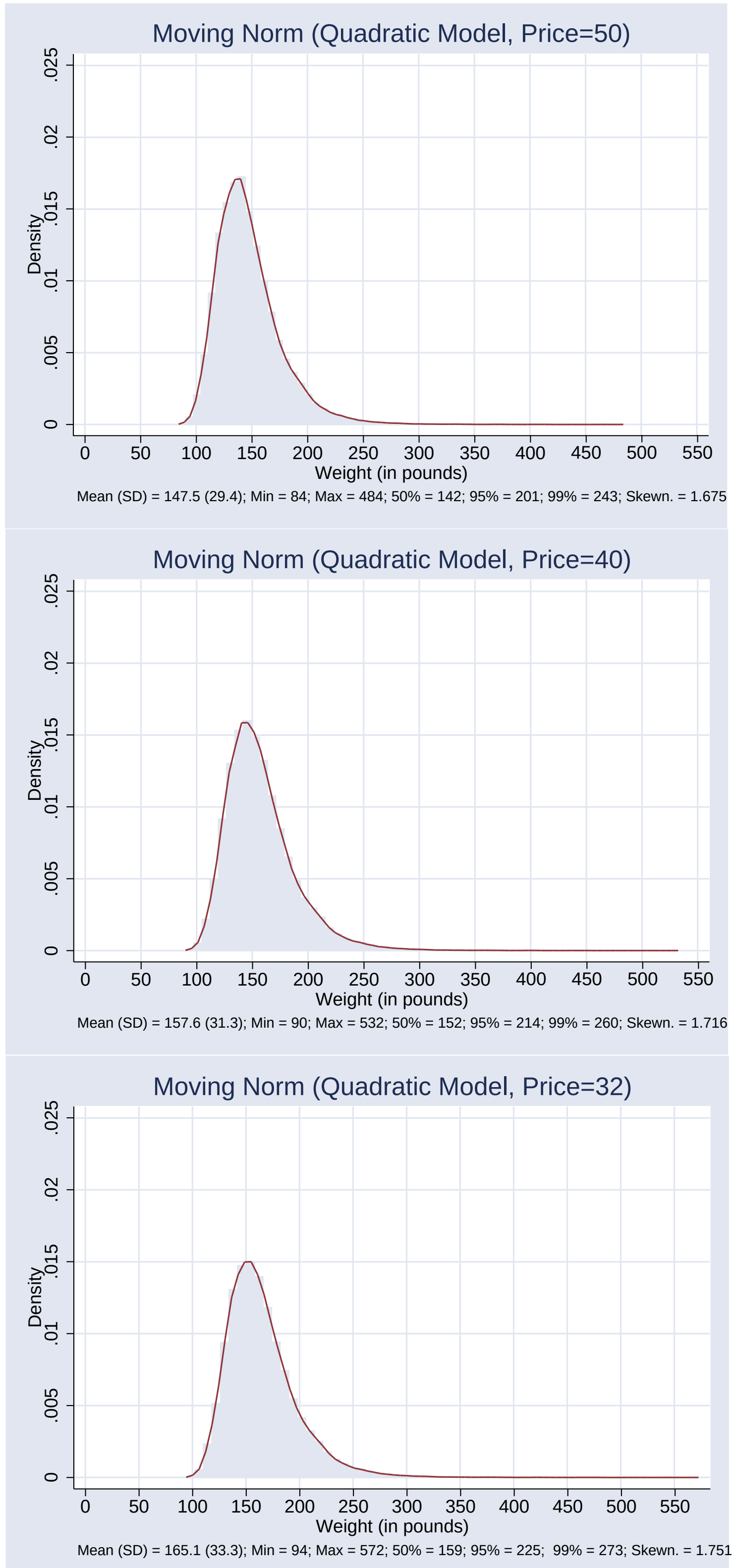

Figure 8: Single Group Price Experiment: Moving Norm, Quadratic Metabolism (with Kernel density estimate plot)

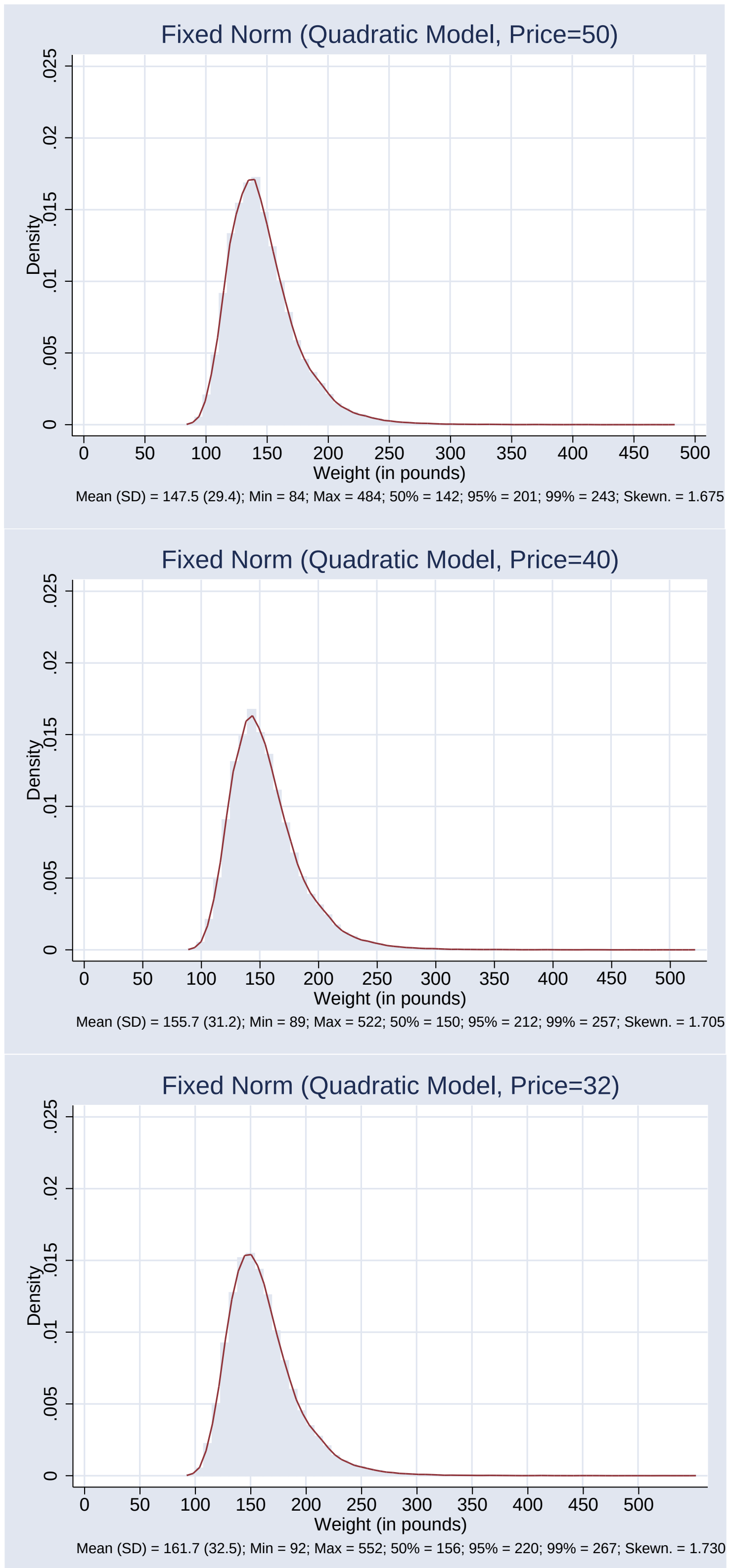

Figure 9: Single Group Price Experiment: Fixed Norm, Quadratic Metabolism (with Kernel density estimate plot)

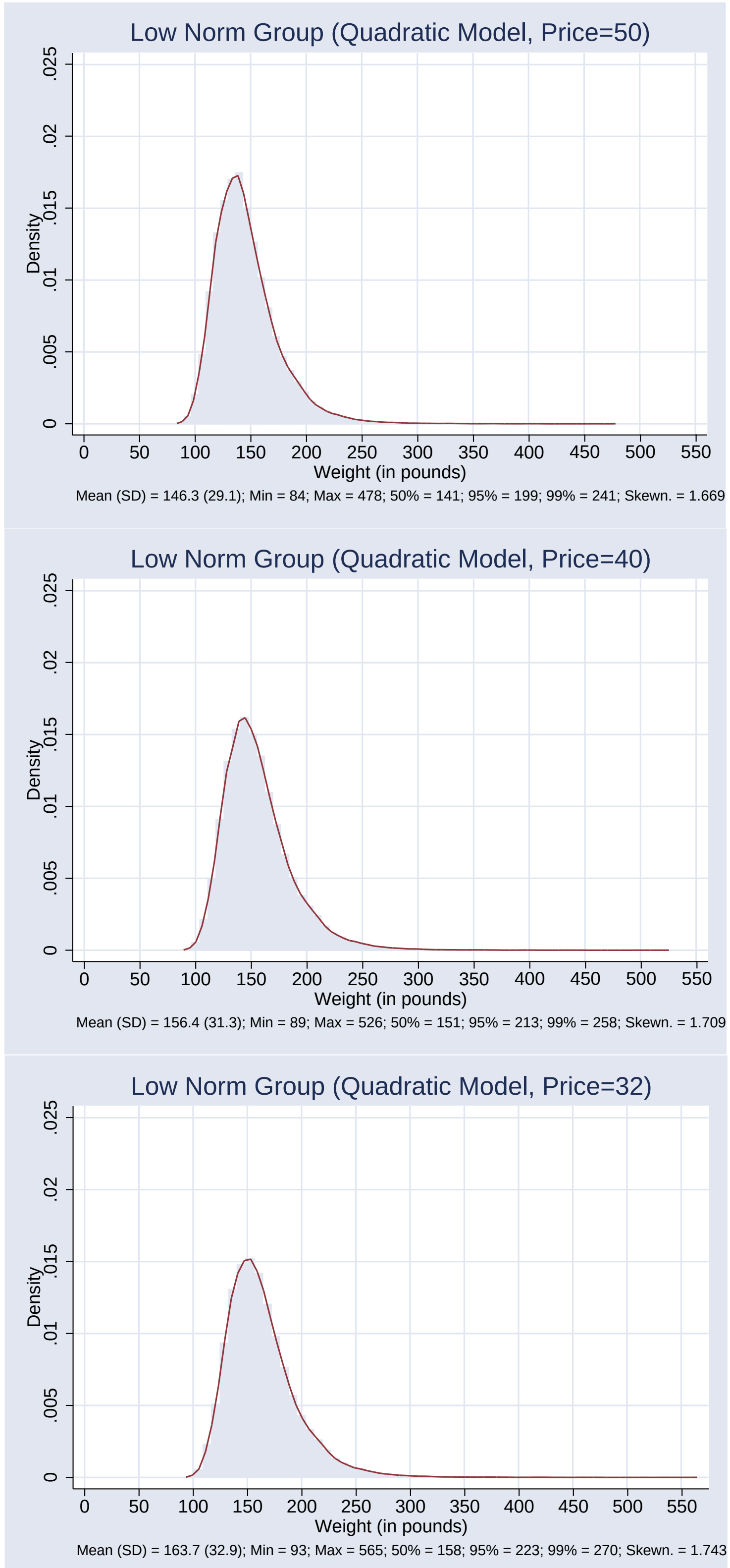

Figure 10: Two Group Price Experiment (Moving Norm): Low Group = 15% below Mean, Quadratic Metabolism (with Kernel density estimate plot)

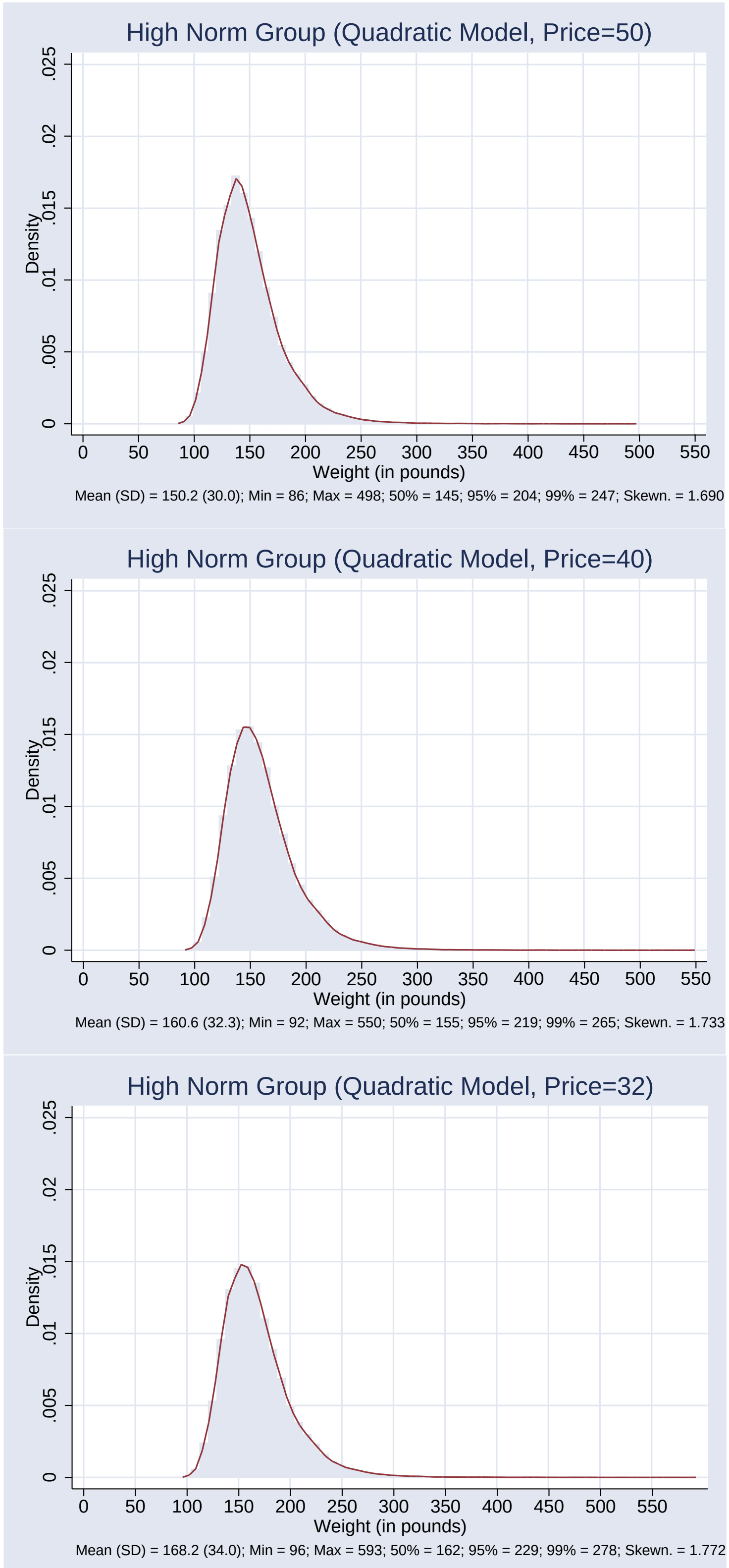

Figure 11: Two Group Price Experiment (Moving Norm): High Group = 5% below Mean, Quadratic Metabolism (with Kernel density estimate plot)