A new approach to quantify the impact of food prices and income on people's eating habits and weight

Sebastien Buttet* and Veronika Dolar†

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Abstract

We propose a new measure for food prices to further examine the impact of changes in food prices and real income on individuals' eating decisions and weight. We calculate *price per calorie* for food consumed away from home and food consumed at home as the dollar amount spent by households on each food category divided by the number of calories consumed. We use our newly constructed time series for price per calorie as an input into a neoclassical model of eating decisions and weight. Our goal is to propose a quantitative explanation for the increase in calories consumed away from home as well as changes in weight for men and women in different age groups between 1971 and 2006. In contrast to previous literature, we find that the impact of changes in food prices and income is quantitatively important as our model accounts for more than seventy percent of the increase in weight for men and women between 1971 and 2006. We also match changes in the fraction of calories consumed away from home well.

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Keywords: Obesity, body weight, food away from home, inter-temporal decisions, food prices.

*Cleveland State University. Email: s.buttet@csuohio.edu.

†University of Minnesota. Email: dola0068@umn.edu. All errors are ours.

1 Introduction

Previous empirical research in health economics show that changes in food prices have little impact on individuals' eating decisions and weight (Chou et al., 2004, Gelbach and Klick, 2007, or Chouinard et al., 2007). For example, Chou et al. (2004) find that the increase in the per capita number of restaurants makes the largest contribution to trends in weight outcomes, followed by increase in the real price of cigarettes, and lastly the decline in food prices. Similarly, Gelbach and Klick (2007) find that as healthful food becomes more expensive relative to unhealthful foods, individuals exhibit higher body-mass index and higher likelihoods of being overweight or obese. However, the quantitative effect of price food changes is small as it accounts for only about one percent of the rise in average body-mass index in the last twenty years.

In this paper, we further examine the impact of changes in food prices and real income on individuals' eating decisions and weight. In contrast to the previous literature, however, we introduce a new measure for food prices which considers the price per calorie consumed rather than prices of specific food items. Using data on food expenditures as well as calories consumed from the US Department of Agriculture between 1971 and 2006, we calculate *price per calorie* for food consumed away from home and food consumed at home as the dollar amount spent by households on each food category divided by the number of calories consumed. The price per calorie has two significant advantages over traditional food prices. First, it provides a simple method for aggregating food items in different categories. Second, it is intuitively appealing as it controls for changes in portion sizes at restaurants (Young and Nestle, 2002). We show that the price of food consumed away from home declined by twenty-seven percent between 1971 and 2006 compared to food eaten at home when changes in calories consumed are taken into account. On the other hand, when using time series for food prices from the Bureau of Labor Statistics, we find that food consumed away from home became more expensive compared to food eaten at home, which seems at odd with the observed increase in the fraction of calories eaten away from home.

We use our newly constructed time series for price per calorie as an input into a dynamic model of eating decisions and weight. Our goal is to propose a quantitative explanation for the increase in calories consumed away from home as well as changes in weight for men and women in different age groups between 1971 and 2006. During the period of interest, the fraction of total daily calories consumed away from home increased substantially, from thirty to forty percent for adult men and eighteen to thirty-five percent for adult women. In addition, the average weight of adult men and women was equal to 176 and 146 pounds in 1971, respectively. Thirty-five years later, men and women each became twenty-pounds heavier, bringing their average weight to 198 and 169 pounds, respectively.

Our model is in the neoclassical tradition with parsimonious assumptions about individual behavior. First, given the relative price of a calorie at and away from home and real income, agents decide how much and where to eat (out or at home) as well as non-food consumption. Second, the body weight law of motion makes eating decisions dynamic. Agents gain weight when contemporaneous calorie consumption is greater than the number of calories required to maintain constant weight, which is determined by the agent's gender, age, height, the activity level, and her current weight. Finally, there is a positive probability that consumers die in each period and this probability depends on weight. Note that although agents do not have access to credit markets, they can smooth utility through food consumption and weight as the following trade-off is at work. Increasing food consumption in the current period yield instantaneous utility but leads to higher future weight and thus possibly lower future utility.

We calibrate the deep parameters of our model in order to match the average weight of adult men and women in 1971 and 1988 as well as the fraction of calories consumed away from home. We find that food consumed away from home and food at home are substitutes and men and women differ in their preferences for food versus non-food and food at home versus food away from home. Given the calibrated parameters, we simulate our model taking changes in price per calorie and real income as exogenous variables and we look at the optimal fraction of calories consumed away from home and weight. In contrast to previous literature, we find that the impact of changes in food prices and income is quantitatively important as our model accounts for more than seventy percent of the increase in weight for men and women between 1971 and 2006. We also match changes in the fraction of calories consumed away from home well.

The remainder of the paper is organized as follows. In Section 2, we describe data about changes in weight, the fraction of calories consumed away from home, the relative price of a calorie consumed at and away from home, and real household income between 1971 and 2006. In Section 3 and Section 4, we develop and calibrate our dynamic model and we conduct our experiments in Section 5. Finally, we offer concluding remarks in Section 6.

2 Nutritional and Economic Data

In this section, we use data from the National Health and Nutritional Examination Survey (NHANES) for three distinct time periods (NHANES I for years between 1971 and 1975, NHANES III for years between 1988 and 1994, and NHANES 2005-2006) to document key facts about changes in weight, the number of calories consumed every day, and the fraction of calories consumed away from home for the years between 1971 and 2006. NHANES is a program of studies administered by the Center for Disease Control (CDC) and designed to assess the health and nutritional status of adults and children in the United States. It is unique in that it combines interviews and physical examinations. Information from interview surveys is self-reported by individuals and consists of answers to demographic, socioeconomic, and dietary questions. The examination component, on the other hand, consists of medical, dental, and physiological measurements, as well as laboratory tests administered by highly trained medical personnel.

In Table 1, we present mean weight and body-mass index (BMI) for adult males and females between age 25 to 64 for the periods 1971-75, 1988-94, and 2005-2006. Information about weight and height comes from the examination component of NHANES. Body-mass index is a measure of body fat based on height and weight that applies to both adult men and women and is calculated as 703 times weight measured in pounds divided by height squared measured in inches squared. Individuals with BMI lower than 18.5 are considered underweight, between 18.5 and 24.9 normal weight, between 25 and 30 overweight, and 30 or greater obese. BMI combined with other information about waist circumference and other factors such as physical activity, cigarette smoking, or low-density cholesterol level gives a risk assessment of developing obese-associated diseases such as heart attacks, diabetes II, strokes, etc.

Table 1: Change in mean weight and body-mass index by age and gender (Std. Dev.)

	Weight (lbs.)			BMI		
Year	1971-1975	1988-1994	2005-2006	1971-1975	1988-1994	2005-2006
Men:						
All (25-64)	175.7 (32.36)	184.0 (37.82)	198.2 (44.43)	25.9	27.1	29.0
Age 25-34	174.9	179.0	191.8	25.5	26.2	28.1
Age 35-44	177.0	187.3	204.9	25.9	27.2	29.6
Age 45-54	177.9	185.9	197.4	26.3	27.3	28.8
Age 55-64	172.5	186.1	198.0	26.1	27.6	29.7
N. Obs.	2574	4966	1399	2574	4966	1399
Women:						
All (25-64)	145.8 (35.94)	155.6 (38.90)	168.9 (46.19)	25.2	26.7	28.8
Age 25-34	139.5	148.3	165.1	23.9	25.4	28.0
Age 35-44	146.1	156.2	163.4	24.8	26.6	27.9
Age 45-54	148.9	162.0	174.0	25.8	27.8	29.9
Age 55-64	150.8	160.6	174.2	26.9	28.1	29.9
N. Obs.	3113	5738	1535	3113	5738	1535

First, men and women between age 25 and 64 each gained more than 22 pounds from 1971 to 2006 and the increase in weight is the largest for the period between 1994 and 2006.[1] For example, men and women between age 25 and 64 gained 8.3 and 9.8 pounds, respectively, between 1971 and 1994 and an additional 14.2 and 13.3 pounds, respectively, from 1994 to 2006. Note that in percentage terms, the increase in weight is larger for

[1]Simple t-tests show that differences in means over time are statistically significant. For example, the difference in mean weight for men between the years 1971-75 and 1988-94 is equal to 8.3, while the standard error of sample-mean differences is equal to 0.63, resulting in a 95 percent confidence interval of (6.7,9.9). Since the p-value associated with a difference of zero is strictly less than 5 percent, we can reject the null hypothesis that the weight distributions for men in periods 1971-75 and 1988-94 have identical mean.

women compared to men. Second, men and women in *all* groups gained weight and the increase in weight measured in pounds is the largest for individuals over 35. Finally, everything else equal, the weight gain puts individuals' health at risk since body-mass index in all age groups increased. Between 1971 and 2006, men and women went from being slightly overweight to overweight/borderline obese as their BMI increased from 25.9 and 25.2, respectively, to 29.0 and 28.8.[2] Next, we analyze the relationship between observed weight and calories consumed.

Mechanically, people gain weight when the number of calories they consume every day is greater than the number of calories required to maintain a constant weight. Information about calories consumed daily is included in the interview part of NHANES and thus is self-reported by individuals rather than directly measured by medical staff. We believe that three possible reasons lead individuals to under-report their daily calorie intake. First, it is hard to remember all food items consumed in an entire day. Second, people who tend to eat in excess of dietary guidelines can feel embarrassed by their eating habits and misreport their food consumption. Finally, if individuals know the interview date in advance, they might change their dietary habits and adjust their calories consumed downward for one day in order to exhibit "good behavior". As a result, we concentrate on the relationship between observed weight and daily calories requirement, rather than relaying on the NHANES data. According to a technical report published by the Food and Nutrition Board of the Institute of Medicine of the National Academies in 2002, the minimum number of calories required to maintain a constant weight depends on gender, age, weight, height, and the activity level. For men, this daily calorie requirement is given by:

$$c^m = 662 - 9.53 \times Age + Activity \times (7.23 \times Weight + 13.706 \times Height) \tag{1}$$

where age is expressed in years, weight in pounds, height in inches, and the activity level is equal to 1, 1.12, 1.27, and 1.45, when the activity level is sedentary, low active, active, and very active, respectively. According to equation (1), the number of daily calories required to maintain constant weight declines as men get older but increases with the

[2] Note that men and women are slightly taller in 2006 compared to 1971, which everything else equal reduces BMI (Komlos, 2009).

activity level, weight, and height. Since men gained weight in the last thirty years, their daily calorie intake must have been greater than c^m. For women, the amount of calories needed to maintain a constant weight is given by:

$$c^w = 356 - 6.91 \times Age + Activity \times (4.25 \times Weight + 18.44 \times Height) \quad (2)$$

In Table 2, we present the number of daily calories required to maintain the mean weight reported in Table 1. We report the calorie requirement as an interval where the lower/upper bounds correspond to the calorie requirement for the lowest/highest activity level. Note that women need fewer calories compared to men in order to maintain their weight. In addition, men and women must have eaten at least 200 extra calories every day to match the weight gain observed in the data. This extra 200 calories is in line with research in the nutrition and medical field as the Dietary Guidelines for Americans published by the U.S. Department of Agriculture shows that people gain 10 pounds per year if they eat an extra 100 calorie every day for one year. Finally, we find that the number of calories self-reported in NHANES surveys is indeed lower compared to the number of calories required to maintain constant weight. For example, men between age 25 to 64 report to eat 2460 calories every day for the period 1971-75, which is lower than the number of calories needed to maintain constant weight when the physical activity level is sedentary. Now that we established the increase in total daily calories intake over time, we focus in another change in dietary habits of Americans: where they eat.

In Table 3, we report the fraction of calories consumed away from home. This information comes from the interview surveys and thus is self-reported by individuals. Individuals report the type of food they ate and the location where they ate it. NHANES imputes a given number of calories for each individual food item. We believe that people have no incentives to misreport the location where they eat and thus use individual answers. The question about where do people eat their meal has changed over time, however. In NHANES I, individuals can choose among the following four locations: at home, in school, in restaurants, and other, while the number of locations increased to fifteen in NHANES III, including at home, in school, in restaurants, fast food, etc. Finally, in NHANES 2005-06, the location question is: "Did you eat this food at home?" and the possible answers are yes, no, refused to answer, do not know, and missing information. We get rid of a

Table 2: Calorie requirement by age and gender

	1971-1975	1988-1994	2005-2006
Men:			
Age 30	(2594, 3592)	(2620, 3630)	(2713, 3764)
Age 40	(2510, 3514)	(2589, 3628)	(2719, 3816)
Age 50	(2416, 3420)	(2478, 3510)	(2564, 3634)
Age 60	(2272, 3254)	(2380, 3410)	(2461, 3527)
Women:			
Age 30	(1924, 2722)	(1961, 2777)	(2038, 2888)
Age 40	(1886, 2699)	(1927, 2759)	(1958, 2803)
Age 50	(1818, 2631)	(1879, 2720)	(1930, 2794)
Age 60	(1740, 2550)	(1793, 2626)	(1862, 2726)

small fraction of missing values or unknowns. To maintain consistency across the three data sets, we define food eaten at home as any food item for which individuals answered at home in NHANES I and III and yes in NHANES 2005-06. We define food eaten away from home as all food items not eaten at home. We then calculate the fraction of calories eaten away from home as one minus the fraction of calories eaten at home.

The fraction of calories consumed away from home for men and women between age 25 to 64 increased by 10.6 and 17.4 percentage points, respectively, from 1971 to 2006 and the increase is the largest for the period between 1971 and 1994.[3] For example, the

[3]Note that our estimates for the fraction of food eaten away from home are higher than those found by Lin et al. (1999) who use data from the Nationwide Food Consumption Surveys (NFCS) for two time periods 1977-78 and 1987-88. In their data set, people report where the food was either bought or made, compared to where the food was eaten in NHANES. Consider the case of an individual who prepares food at home and brings it and eat it at school or work. In NHANES, the number of calories consumed is counted as eaten away from home, while it is counted as eaten at home in NFCS. On the other hand, consider the case of an individual who order a meal at a restaurant and brings part or all of it back to her home and eats it there. In NHANES, the number of calories consumed is counted as eaten at home, while it is counted as eaten away from home in NFCS. If there are more people who prepare their food at home and eat it outside compared to people who buy their food at restaurants and bring it back home, our estimates for the fraction of food eaten away from home are higher than those found by Lin et al. (1999).

Table 3: Percentage of calories consumed away from home by age and gender

	1971-1975	1988-1994	2005-2006
Men:			
All (25-64)	29.9	39.4	40.5
Age 25-34	36.6	43.1	44.4
Age 35-44	32.8	41.8	41.8
Age 45-54	25.9	38.3	40.6
Age 55-64	22.4	28.3	33.3
Women:			
All (25-64)	18.5	33.6	35.9
Age 25-34	21.6	36.4	38.1
Age 35-44	20.3	36.0	36.1
Age 45-54	17.5	32.9	36.4
Age 55-64	13.5	25.0	31.7

fraction of calories consumed away from home for all men and women increased by 9.5 and 15.1 percentage points, respectively, from 1971 to 1994 and an additional 1.1 and 2.3 percentage points from 1994 to 2006. In addition, the fraction of calories away from home is greater for men compared to women in all age groups and years, it declines with age, and it is less than fifty percent, indicating that people still eat most of their food at home. Next, we relate changes in weight and the fraction of calories consumed away from home, on the one hand, to changes in relative food prices and real income, on the other hand.

In Table 4, we present changes in the relative price of food at and away from home between 1971 and 2006 as well as changes in real household income. Because portions at restaurants and fast food significantly increased in the last thirty years, we use the price per calorie rather than regular prices to assess changes in the relative price of food (Young and Nestle, 2002). We calculate the price of one calorie eaten at/away from home as total expenditures divided by calorie consumed at/away from home. For each year between 1971 and 2006, the per calorie price of food away from home, $p_{A,t}$, and food at home, $p_{H,t}$, are equal to:

$$p_{A,t} = \frac{\alpha_{A,t} I_t}{\text{Calories}_{A,t}}, \quad p_{H,t} = \frac{\alpha_{H,t} I_t}{\text{Calories}_{H,t}} \tag{3}$$

where $\alpha_{A,t}$ and $\alpha_{H,t}$ denote the expenditure share on food away and at home, respectively, and I_t represents real disposable income in period t. We use data on household expenditures published by USDA to estimate $\alpha_{A,t}$ and $\alpha_{H,t}$. For periods 1971-75, 1988-94, and 2005-06, the average expenditure share on food away from home is equal to 3.5, 4.2, and 4.1 percent, respectively, while the expenditure share on food at home is equal to 9.9, 6.8, and 5.7 percent, respectively. Information about nominal disposable income comes from the Bureau of Economic Analysis (BEA) and we use the consumer price index (CPI) published by BLS to calculate the real disposable income expressed in 2006 dollars.

Table 4: Changes in per calorie food prices and real income

	1971-1975	1988-1994	2005-2006
Relative price (Away/Home)	1.61	1.44	1.34
Mean Real Income in 2006 $			
All (25-64)	$59,742	$65,992	$74,089
Age 25-34	52,849	54,727	59,609
Age 35-44	63,850	71,729	76,654
Age 45-54	67,095	77,549	83,758
Age 55-64	54,990	62,811	73,450

The relative price of food away from home decreased by 16.8 percent for the entire period and the decline is the largest for the period between 1971 and 1994. The relative price of food away from home declined by 10.6 percent from 1971 to 1994 and by an additional 6.9 percent between 1994 and 2005. Note that the relative price of food away from home is always greater that one, implying that eating out is more costly than eating at home, even after adjusting for differences in the number of calories. In addition, we looked at changes in food prices published by BLS. We find that the price of food consumed away from home increased by 40 percent from 1971 to 1994 and by an additional 5 percent between 1994 and 2005. The increase in food prices away from home is clearly at odd with the observed increase in the fraction of calories eaten away from home.

On the other hand, real income increased by 24 percent from 1971 to 2006 and the increase in real income is the largest in percentage terms between 1994 and 2006. In the next section, we propose a calibrated dynamic optimization model to quantify the impact of changes in food prices and real income on people eating decisions and weight.

3 A Dynamic Optimization Model of Eating Decisions

Time is discrete and infinite, $t = 1, 2, ...$ In each period, agents decide how much and where to eat (out or at home) as well as non-food consumption. We let a_t and h_t be the number of calories consumed away and at home, respectively, and c_t^{nf} represents non-food consumption. Calories away and at home are aggregated using a constant elasticity of substitution (CES) function to obtain food consumption:

$$c_t^f = (\eta a_t^\rho + (1-\eta) h_t^\rho)^{\frac{1}{\rho}} \tag{4}$$

with $\eta \in (0, 1)$ and $\rho \in (-\infty, 1]$. The positive parameter η can be viewed as reflecting the consumer's taste. For a consumer who likes to eat at home, η is small. Conversely, a large value for η indicates that the consumer likes eating away from home. Later in the paper, we estimate the value for η and show that it differs greatly between men and women. On the other hand, food away and at home are perfect substitutes, Cobb-Douglas, or perfect complements when the parameter ρ is equal to one, zero, or minus infinity, respectively.

Preferences of the representative agent are of constant relative risk aversion (CRRA) form and are given by:

$$U(c_t^f, c_t^{nf}) = \begin{cases} \frac{[(c_t^f)^\alpha (c_t^{nf})^{1-\alpha}]^{1-\sigma}-1}{1-\sigma} & \text{with } \sigma > 0 \quad \text{and } \sigma \neq 1 \\ \alpha \log(c_t^f) + (1-\alpha)\log(c_t^{nf}) & \text{if } \sigma = 1 \end{cases} \tag{5}$$

where the inter-temporal elasticity of substitution between consumption in any two periods is equal to $\frac{1}{\sigma}$ and $\alpha \in (0, 1)$ represents the food consumption share. The smaller σ is, the more willing are households to substitute consumption over time.

As in Yaari (1965), the representative agent makes consumption decisions in an environment where she is uncertain how long she will live. At the beginning of each period, a special coin is tossed to determine whether she survives the period or dies. We denote by $\pi(W_t)$ the conditional probability that a consumer with weight W_t makes it to the next time period provided that she is alive at the beginning of the period. In addition, the death probability is inverted U-shape which implies that agents who are over- or underweight have a greater chance to die. Finally, death is an absorbing state and consumer receives utility $\underline{U}$ forever if she dies.

The expected utility discounted to period one is equal to:

$$\sum_{t=1}^{+\infty} \beta^{t-1}(\Pi_{s=1}^{t-1}\pi(W_s))(\pi(W_t)U(c_t^f, c_t^{nf}) + (1-\pi(W_t))\underline{U}) \tag{6}$$

where the parameter $\beta \in (0,1)$ is the pure time discount factor. We restrict the consumption set for food and non-food consumption to ensure that contemporaneous preferences are bounded from below and death is never an optimal choice. We assume that food and non-food consumption must be greater than $\underline{c}^f > 0$ and $\underline{c}^{nf} > 0$, respectively, and that $\underline{U} \leq U(\underline{c}^f, \underline{c}^{nf})$ so that it is never optimal for people to eat less than $\underline{c}^f$ and consume less than $\underline{c}^{nf}$ in any period. Note that the representative agent can die in two very different ways. In the short-run, she dies if she eats or consumes less than the subsistence levels. In the long-run, the probability of death increases if she is either over- or underweight.

The inter-temporal weight law of motion links weight in the next period to current weight and calorie consumption:

$$W_{t+1} = W_t + \lambda(a_t + h_t - c(W_t)) \tag{7}$$

where $\lambda > 0$ is a parameter that converts calorie consumption into weight gain and the function $c(W_t)$ denotes the daily calorie requirement in order to maintain a constant weight with $c' > 0$. As a result, consumers gain weight when the total calorie intake from food away and at home is greater than $c(W_t)$.[4]

[4] Even though the equilibrium weight depends on how much agents exercise, the level of physical activity is exogenous in our model, in contrast to Lakdawala et al. (2005). We are comfortable with this assumption because Cutler et al. (2003) show that the average level of physical activity did not change much since 1970.

Finally, the budget constraint of the representative agent is given by:

$$c_t^{nf} + p_{ht}h_t + p_{at}a_t = I_t \tag{8}$$

where we normalized the price of non-food to one, p_{ht} and p_{at} are the real price of food at and away from home, respectively, and agents are endowed with real income I_t. Note that a more realistic setting would include credit markets to allow consumers to smooth utility over time. The rise in credit availability and use between 1971 and 2006 might be an important factor for explaining individuals' decisions to eat at restaurants (Levy, 2007). In our model, agents smooth utility through food consumption and weight as the following trade-off is at work. Increasing food consumption in the current period yield instantaneous utility but leads to higher weight and thus possibly lower utility in the future.

For any given sequence of prices and income, $\{p_{ht}, p_{at}, I_t\}_{t\geq 1}$, and an initial weight, W_1, the representative agent chooses an optimal sequence of calories from food away and at home as well as non-food consumption, $\{a_t, h_t, c_t^{nf}\}_{t\geq 1}$, to maximize the expected utility discounted to period one in equation (6) subject to the aggregation equation (4), the budget constraint (8), the weight law of motion (7), and non-negativity constraints for calorie and non-food consumption.

We substitute the budget constraint and the weight law of motion into consumer's utility. We take first-order conditions with respect with food away from home, a_t, and food at home, h_t.

$$\begin{aligned} \frac{\alpha\eta {a_t}^{\rho-1}}{\eta {a_t}^{\rho} + (1-\eta){h_t}^{\rho}} - \frac{p_{at}(1-\alpha)}{I - p_{at}a_t - p_{ht}h_t} &= \frac{\lambda\beta\pi'(W_{t+1})(U(c_{t+1}^f, c_{t+1}^{nf}) - \bar{U})}{1 + (1-\sigma)U(c_t^f, c_t^{nf})} \\ \frac{\alpha(1-\eta) {h_t}^{\rho-1}}{\eta {a_t}^{\rho} + (1-\eta){h_t}^{\rho}} - \frac{p_{ht}(1-\alpha)}{I - p_{at}a_t - p_{ht}h_t} &= \frac{\lambda\beta\pi'(W_{t+1})(U(c_{t+1}^f, c_{t+1}^{nf}) - \bar{U})}{1 + (1-\sigma)U(c_t^f, c_t^{nf})} \end{aligned} \tag{9}$$

Note that consumer's utility is not strictly concave because the survival probability depends on consumer's weight. As a result, it not clear whether first-order conditions are sufficient for optimality. Although we do not offer a formal proof, we check that consumer's optimal allocation is utility maximizing (locally) in our simulations.

We analyze the above system of equations when prices, income, and quantities are constant over time. The steady-weight weight is equal to $W^* = c^{-1}(a^* + h^*)$, where consumption of food away and at home, a^* and h^*, are found by solving the following system of equations:

$$\frac{\alpha\eta a^{*\rho-1}}{\eta a^{*\rho}+(1-\eta)h^{*\rho}}-\frac{p_a(1-\alpha)}{I-p_a a^*-p_h h^*}=\frac{\alpha(1-\eta)h^{*\rho-1}}{\eta a^{*\rho}+(1-\eta)h^{*\rho}}-\frac{p_h(1-\alpha)}{I-p_a a^*-p_h h^*}$$
$$\frac{\alpha\eta a^{*\rho-1}}{\eta a^{*\rho}+(1-\eta)h^{*\rho}}-\frac{p_a(1-\alpha)}{I-p_a a^*-p_h h^*}=\frac{\lambda\beta\pi'(c^{-1}(a^*+h^*))(U(c^{f^*},c^{nf^*})-\bar{U})}{1+(1-\sigma)U(c^{f^*},c^{nf^*})} \tag{10}$$

with $c^{f^*}=(\eta a^{*\rho}+(1-\eta)h^{*\rho})^{\frac{1}{\rho}}$ and $c^{nf^*}=I-p_a a^*-p_h h^*$. In the next section, we calibrate the model to the average weight of American men and women for the period between 1971-1988 as well as the fraction of calories consumed away from home.

4 Calibration

First, we set the parameters of the weight law of motion in equation (7). According to the dietary guidelines from the US Department of Agriculture, people gain ten pounds per year if they eat an extra one hundred calories every day above and beyond the recommended daily calorie intake, which implies that $\lambda = 2.7397 \times 10^{-4}$. We assume a low physical activity level for men and women (Activity = 1.12) in the daily calorie requirement functions in equations (1) and (2), respectively. As a result, the steady state weight of men and women W^{*m} and W^{*f}, are equal to:

$$W^{*m}=\frac{a^*+h^*-662+9.53\times\text{age}-15.35\times\text{height}}{8.09}$$
$$W^{*f}=\frac{a^*+h^*-356+6.91\times\text{age}-20.65\times\text{height}}{4.76} \tag{11}$$

Second, we assume that the death probability is given by the following expression:

$$\pi(W_t)=1-\pi_a\times hr(W_t) \tag{12}$$

where $\pi_a \in (0,1)$ captures the death likelihood for reasons unrelated to obesity and $hr(W_t)$ denotes the increased likelihood of death due to being over or underweight. Throughout the rest of the paper, we set $\pi_a = 0.01$. We use the work of Allison et al. (1999) to calibrate the function $hr(W_t)$. Allison et al. (1999) report the hazard ratios of death based on six large prospective cohort studies where subjects are placed into two distinct groups: the control group is comprised of individuals whose body-mass index (BMI) is between twenty-three and twenty-five; the treated group consists of individuals with BMI higher than twenty-five. In Table 5, we present their results and it is clear that the probability of dying tends to increase with BMI. For example, in the Alameda Country Health Study, people with BMI between thirty and thirty-five have 1.36 more chance to die compared to people with normal weight, and the hazard ratio increases to 2.79 for people with BMI greater than thirty-five.[5]

We use the regression algorithm in Judd (1998, p.223) to approximate the hazard rate function with Chebyshev polynomials, $\{T_i\}$, for body-mass index in the interval $[19, 37]$. This procedure consists of evaluating a degree n polynomial function at $m > n$ pre-determined nodes. We choose a polynomial of degree six, $hr(W_t) = \sum_{i=0}^{i=6} a_i T_i(W_t)$, and we search for the best coefficients, $\{a_i\}$, to match the relationship between the observed average hazard ratio and BMI at seven nodes. The estimated coefficients $\{\hat{a}_i\}$ are equal to $\{1.309, 0.302, 0.317, 0.039, 0.064, 0.035, 0.026\}$.

Third, we set the preference parameter $\sigma = 2$ as the implied value for the inter-temporal elasticity of substitution is commonly used in macroeconomic models and we fix the pure discount factor equal to $\beta = 0.96$ per year (see the collection of papers in Cooley, 1995 or Mehra and Prescott, 1985).

Finally, we use the two first-order conditions in equation (10) for the periods 1971-75 and 1988-94 to calibrate the last deep parameters of the model. We assume that two of these parameters, the elasticity of substitution between food at and away from home, ρ, and the utility from death, $\underline{U}$, are common to men and women. On the other hand, we let the food share, α, and the parameter η to differ across gender. Prices of food away and at home come from Table 4 in the data section and mean income is for all adults (age 25-64). We summarize the calibrated parameter values in Table 6.

Our calibration yields two interesting results. First, food away from and at home are substitutes since the elasticity of substitution parameter $\rho = 0.718$. As a result, the

[5] Fontaine, Redden, Wang, Westfall, and Allison (2003) calculate years of life lost due to obesity. The maximum years of life lost for white men twenty to thirty years of age with a severe level of obesity (BMI > forty-five) is thirteen years and eight for white women.

Table 5: Hazard Ratios for various BMI categories

BMI Category	< 23	[23 - 25)	[25 - 26)	[26 - 27)	[25 - 28)	[28 - 29)	[29 - 30)	[30-35]	> 35
Alameda	1.39	1.00	0.98	0.86	1.20	1.26	1.23	1.36	2.79
Framingham	1.12	1.00	0.96	1.11	1.04	1.08	1.41	1.60	1.94
Tecumseh	1.20	1.00	1.18	0.89	1.12	0.92	0.94	1.45	1.87
Cancer Society	1.07	1.00	1.02	1.06	1.08	1.14	1.21	1.35	1.72
Nurses	1.06	1.00	0.92	0.96	1.09	1.21	1.32	1.49	1.89
NHANES	1.04	1.00	0.96	1.11	0.96	1.40	1.06	1.33	1.68

Source: Allison, Fontaine, Manson, Stevens, and VanItallie (1999)

Table 6: Calibrated Parameters

Parameter	Value	Parameter	Value
σ	2	ρ	0.718
λ	2.74×10^{-4}	$\underline{U}$	0.959
η^{men}	0.530	α^{men}	0.075
η^{women}	0.492	α^{women}	0.051

fraction of calories consumed at home should decrease following a decline in the relative price of food away from home. Note that Reed et al. (2005), using a co-integration method, estimate demand elasticity for various food items and also find that food away from home and at home are substitutes. Second, men and women differ considerably in their preferences for food versus non-food goods and food at home versus food away from home. The food share, α, and the preference parameter for food away from home, η, are greater for men compared to women. Note that the heterogeneity across gender is not counter-intuitive since men tend to eat more than women and they also eat more away from home. In the next section, we use our calibrated version to assess the impact of changes in relative food prices and real income on eating habits and weight of Americans between 1971 and 2006.

5 Simulations

In Tables 7 and 8, we present results of our first experiment. We consider the impact of changes in food prices and real income together between 1971 and 2006 on mean weight and the fraction of calories consumed away from home for men and women, overall and by age group. Note that, because of the way the model is calibrated, we match calories away from home and weight perfectly, for all men (age 25-64) for the periods 1971-75 and 1988-94 and for all women (age 25-64) for the period 1971-75.

Table 7: Changes in mean weight and body-mass index by age and gender

	Weight (lbs.)			BMI		
Year	1971-1975	1988-1994	2005-2006	1971-1975	1988-1994	2005-2006
Men:						
All (25-64)	175.7	184.0	191.1	25.9	27.1	28.0
Age 25-34	169.2	172.6	182.9	24.6	25.3	26.8
Age 35-44	178.2	186.4	208.7	26.1	27.1	30.1
Age 45-54	181.2	190.5	196.8	26.8	28.0	28.7
Age 55-64	175.6	189.7	210.3	26.5	28.1	31.5
Women:						
All (25-64)	145.8	152.3	169.9	25.2	26.1	29.0
Age 25-34	139.0	142.0	148.4	23.8	24.3	25.2
Age 35-44	146.6	153.0	155.2	24.9	26.1	26.5
Age 45-54	151.6	156.3	158.2	26.3	26.8	27.1
Age 55-64	147.2	152.9	167.5	26.5	26.8	28.7

Table 8: Percentage of calories consumed away from home by age and gender

	1971-1975	1988-1994	2005-2006
Men:			
All (25-64)	29.9	39.4	46.1
Age 25-34	27.2	35.0	41.8
Age 35-44	30.9	40.5	44.1
Age 45-54	32.7	42.5	47.9
Age 55-64	29.3	39.2	46.0
Women:			
All (25-64)	18.5	26.1	31.2
Age 25-34	15.7	22.4	28.4
Age 35-44	19.3	27.2	32.4
Age 45-54	20.6	28.8	33.9
Age 55-64	16.5	26.2	32.1

We first review the results for all men and women (age 25-64). The model accounts for 68 percent and all of the weight increase between 1971 and 2006 for men and women, respectively. It also accounts for 73 percent of the increase in the fraction of calories consumed away from home between 1971 and 2006 for women, and more than one hundred percent for men. One simple way to interpret our results is that people eat more and thus gain weight as their real income increased over time. In addition, they eat out more because the relative price of food away from home declined.

We further assess the model performance by looking at its predictions for weight and calorie consumed away from home for men and women in different age groups. In the initial period 1971-75, the match for weight is close for men in age group 35-44 and for women in age group 25-34 and 35-44. This is a validating result for our model because we did not set any of the deep parameters in the calibration to match weight for men and women in these age groups. However, the percentage of calories consumed away from home is well off compared to the data.

Because the model is not able to match weight and calories away from home for men and women in different age group in the initial period 1971-75, it is difficult to interpret its predictions for changes in weight and calories away from home between 1971 and 2006. In our second experiment, we allow the preference parameters η and α to differ by age and gender. We choose them to perfectly match weight and calories away from home for men and women in all age groups for the initial period 1971-75, while keeping the other parameters of the model constant (see Table 9).

Table 9: Preferences Parameters η and α by age and gender

	η		α	
	Men	Women	Men	Women
Age 25-34	0.559	0.519	0.085	0.053
Age 35-44	0.537	0.501	0.075	0.049
Age 45-54	0.508	0.477	0.071	0.050
Age 55-64	0.506	0.462	0.071	0.054

The parameters η and α differ considerably by age and gender. First, the food away from home share, η, is always higher for men compared to women for all age groups. In addition, it decreases with age for both men and women. These two results are intuitive since the demand for food away from home is greater for men compared to women and declines with age. Second, the food share parameter, α, is greater for men compared to women and declines with age for men.

In Tables 10 and 11, we present results of our second experiment. We consider the impact of changes in food prices and real income together on mean weight and the fraction of calories consumed away from home, in a model where the preferences parameters η and α for men and women are given in Table 9. Not surprisingly, the match between model and data for weight and the fraction of calories consumed away from home is perfect for men and women in all age groups in the initial period 1971-75.

Table 10: Changes in mean weight and body-mass index - Heterogenous agents

	Weight (lbs.)			BMI		
Year	1971-1975	1988-1994	2005-2006	1971-1975	1988-1994	2005-2006
Men:						
Age 25-34	174.9	181.7	193.3	25.5	26.6	28.3
Age 35-44	177.0	185.1	189.8	25.9	26.9	27.4
Age 45-54	177.9	185.4	188.8	26.4	27.2	27.6
Age 55-64	172.5	184.1	198.8	26.5	27.3	29.8
Women:						
Age 25-34	139.5	143.8	154.3	23.9	24.6	26.1
Age 35-44	146.1	150.4	153.6	24.8	25.7	26.2
Age 45-54	148.9	155.1	157.2	25.8	26.6	27.0
Age 55-64	150.8	175.3	184.8	26.9	30.7	31.7

The model accounts for all of the weight increase between 1971 and 2006 for men in age group 25-34 and 55-64, respectively, and 46 and 56 percent of the weight increase for men in age group 35-44 and 45-54, respectively. On the other hand, it accounts for 58, 43, and 33 percent of the weight increase between 1971 and 2006 for women in age group 25-34, 35-44, and 45-54, respectively and more than hundred percent of the weight

Table 11: Percentage of calories consumed away from home - Heterogenous agents

	1971-1975	1988-1994	2005-2006
Men:			
Age 25-34	36.6	46.4	53.4
Age 35-44	32.8	42.8	48.7
Age 45-54	25.9	34.8	40.1
Age 55-64	22.4	27.3	29.8
Women:			
Age 25-34	21.6	29.9	36.7
Age 35-44	20.3	28.9	34.5
Age 45-54	17.5	24.6	29.4
Age 55-64	13.5	19.1	24.1

increase for women in age group 55-64.

As far as the fraction of calories away from home is concerned, the model accounts for 97 and 68 percent of the increase between 1971 and 2006 for men in age group 45-54, and 55-64, respectively, and more than hundred percent of the increase for men below age 45. On the other hand, it accounts for 92, 90, 63, and 58 percent of the increase in the fraction of calories consumed away from home between 1971 and 2006 for women in age group 25-34, 35-44, 45,54, and 55-64, respectively.

It is time to evaluate our work. Using a simple neoclassical model of eating decisions, we showed that changes in food prices and real income have a strong quantitative impact on how much and where people eat. We have confidence in our results because, throughout the analysis, we kept the number of parameters in our model small and we were able to identify all economic parameters with microeconomic facts about weight and the fraction of calories consumed away from home. In addition, we used direct evidence from medical research to calibrate the weight law of motion and the health impact of obesity. To end our analysis, we present in Table 12 the price, cross-price, and income elasticity of food away and at home as well as weight for men and women in age group 25-64 for the period between 1971 and 2006. Our definition of elasticity is standard. For example, the cross-price elasticity of food away from home with respect to price at home is equal to $\epsilon_{a,p_h} = \frac{\%\Delta a}{\%\Delta p_h}$.

Table 12: Price, Cross-Price, and Income Elasticities between 1971 and 2006

	p_a	p_h	I
Men (Age 25-64)			
a	-2.62	1.13	0.75
h	1.02	-0.81	-0.19
W	-0.11	-0.39	0.15
Women (Age 25-64)			
a	-3.40	0.82	0.88
h	0.73	-1.05	-0.08
W	-0.07	-0.46	0.22

Elasticity values have the expected sign but differ in magnitude compared to existing estimates in the literature. First, the price elasticity for food away from home is equal to -0.69 in Reed et al. (2005) (later RLH) compared to -2.6 and -3.4 for men and women, respectively, in our model. Second, the price elasticity for food at home ranges from -0.60 for cereal and bakery to -0.98 for fruits and vegetable in RLH comapred to -0.8 and -1.1 for men and women, respectively, in our model. Finally, we find that the income elasticity for food away from home is positive but lower than the estimate of 1.38 in RLH. Interestingly enough, the income elasticity for food at home is negative, i.e. food at home is an inferior good, which is consistent with cross-sectional evidence that wealthier households tend to eat out more.

Our estimates for price and cross-price elasticity for food at home and food away from home have clear implications for the weight price elasticity. Individuals gain weight as the price of food away from home and food at home declines. Using a static model, Schroeter et al. (2008) study the impact of a sin tax on food away from home on people's weight. They find that, when food away from home and food at home are substitutes, the effect of such a tax on people's weight is ambiguous. In our dynamic neoclassical framework, we showed that men and women gained weight following a decline in the price of food away from home.

6 Concluding Remarks

In this paper, we proposed a stochastic dynamic optimization model to study the quantitative impact of changes in food prices on the eating habits of Americans and their weight between 1971 and 2006. After a careful calibration of the model using available evidence from medical research, we found that changes in food prices altogether can account for more than seventy percent of the increase in people's weight and the fraction of calories consumed away from home. In addition, we find that men and women in different age groups are quite heterogenous in their preferences for food overall and for food away from home.

We examined the effect of prices and income on people's weight in a model where agents are fully rational. However, evidence from behavioral and neuroeconomics show that eating decisions are complex and heavily influenced by environmental factors (Cawley, 1999 or McClure et al., 2007). For example, people make very different food choices when their decisions are made "on the spot" or in advance (Rogers et al., 2007). We believe that assessing the impact of changes of food prices and real income on people's weight in a model where agents are less than fully rational would be a worthwhile enterprize. We leave this task for future research.

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