How much are food price changes to blame for the weight increase of Americans?

Sebastien Buttet* and Veronika Dolar†

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Abstract

In the last thirty years, Americans gained on average twenty-two pounds and changed their eating habits in two dramatic ways. First, they eat more, as evidenced by a twenty-three percent increase in average total daily calorie intake. Second, they altered the type of food that they eat. Total daily calories intake coming from low-nutrient-dense food (added sugars, added fats, and flour and cereals) increased by thirty-seven percent. On the other hand, consumption of high-nutrient-dense food (fruits and vegetables, dairy, meat, eggs, and nuts) stayed roughly constant. Over the same period of time, the real price of low-nutrient-dense food declined by sixteen percent, while the real price of high-nutrient-dense food increased by twenty-five percent. We propose a stochastic dynamic optimization model to study the quantitative impact of changes in relative food prices on the eating habits and weight of Americans. After calibrating the model using evidence from medical research, we find that changes in food prices account for less than five percent of the increase in average weight of Americans. We compare our results to existing estimates in the literature.

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

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

1 Introduction

In the last thirty years, Americans changed their eating habits in two dramatic ways. First, they eat more, as evidenced by the twenty-three percent increase in average total daily calorie intake from 2180 calories in 1977 to 2681 in 2005. Second, they altered the type of food that they eat. Total daily calories intake coming from food with low-nutrient density (added sugars, added fats, and flour and cereals) increased by thirty-seven percent. On the other hand, the consumption of food with high-nutrient density (fruits and vegetables, dairy, and meat, eggs, and nuts) slightly increased by four percent.[1]

These changes in eating habits, coupled with a decline in physical activity, had dramatic effects on people's weight and the fraction of obese adults in the United States (Lakdawalla et al., 2005 and Cutler et al., 2003); Americans gained on average twenty-two pounds and the obesity prevalence more than doubled, from fifteen percent in 1977 to more than thirty-five percent in 2005. At the same time, a growing consensus has emerged in the medical field that being overweight or obese is associated with negative health outcomes and in some cases loss of productivity at work. As a result, it is key that we, social scientists, better understand the underlying causes of obesity and design sound policies aimed at reversing the trend.

In this paper, we propose a stochastic dynamic optimization model to assess the quantitative impact of changes in relative food prices on the eating habits and weight of Americans.[2] Although several existing papers study the relationship between food prices and people's eating habits and weight, estimates differ greatly and no consensus has emerged in the literature. On the one hand, direct experiments at work sites or school cafeterias show that purchases of healthy food increase substantially following price cuts on either low-fat

[1]High-nutrient-dense food is food that provides a substantial amount of vitamins and minerals and relatively few calories. Low-nutrient-dense food includes high energy foods with poor nutritional profiles (sometimes referred to as "empty calories").

[2]Finkelstein et al. (2005) provide a comprehensive review of the literature on the various obesity causes.

vending machines snacks or fresh fruits and vegetables (French et al., 2001). On the other hand, estimates from the empirical literature find a more modest impact of food prices on either people's weight or the probability of being obese (Chou et al., 2004 and Gelbach et al., 2007). Our approach differs from existing studies in two important ways. First, we look at the quantitative impact of food prices in a stochastic dynamic optimization model of eating decisions where, in the spirit of Levy (2002), agents realize that current food choices affect future weight and state of health. Second, we introduce a new method for calculating per calorie food prices. We construct an aggregate time series for the average price per calorie of two food categories between 1977 and 2005: food with high-nutrient density (fruits and vegetables, dairy, meat, eggs, and nuts) and food with low-nutrient density (added sugars, added fats, and flour and cereal products). During the period of interest, we find that the price of low-nutrient-dense food has declined by sixteen percent, while the price of high-nutrient-dense food increased by twenty-five percent.

In our model, agents care about two types of food, "high-nutrient-(dense)" and "low-nutrient-(dense)", as well as a non-food consumption good. Their preferences are quasi-linear and high-nutrient and low-nutrient food are aggregated according a constant elasticity of substitution (CES) function, which allows us to consider different scenarios where low- and high-nutrient food are either complements or substitutes.[3] Given the relative price of food, agents decide what fraction of their real income to spend on either type of food as well as the non-food good. The maximization problem is dynamic because agents' weight and state of health in future periods depend on their current weight as well as calorie intake in the current period. The maximization problem is stochastic as there is a positive probability that the representative agent dies in each period and this probability depends on weight.

[3] Schroeter et al. (2008) show that the impact of a tax on high-calorie food on people's weight critically depends on the relationship between high-calorie and low-calorie food. They find that, when high-calorie and low-calorie food are complements, a tax on high-calorie food lead to a weight decrease. However, when high-calorie and low-calorie food are substitutes, the effect of a tax on high-calorie food on people's weight is ambiguous.

After calibrating our model using evidence from medical research, we find that calorie consumption of high-nutrient food declines by roughly twenty-one percent, while calorie consumption of low-nutrient food increases by sixteen and a half percent. Overall, total calorie consumption increases which implies a net gain of one pound for the steady state weight. The increase in weight predicted by the model comes short of the twenty-two pounds gain that is observed in the data. The reason is that increases in calorie consumption of low-nutrient food are offset by decreases in calorie consumption of high-nutrient food. As a result, increases in total calories and thus weight are very modest.

The remainder of the paper is organized as follows. In Section 2, we review parts of the literature that studies the impact of food prices on people's dietary choices and weight. In Section 3, we describe the data about body weight, daily calorie intake, and the relative price of high-nutrient and low-nutrient food. In Section 4 and Section 5, we develop and calibrate our infinite horizon model. In Section 6, we conduct our experiments. We also derive modeling implications from a comparative statics analysis. Finally, we offer some concluding remarks in Section 7.

2 Background

In this section, we review two branches of the literature, experimental studies and econometric analysis, that study the effects of food prices on people's eating decisions and obesity.

2.1 Experimental Studies

French et al. (2001) examine the effect of pricing and promotion strategies on purchases of low-fat snacks from vending machines in twelve schools and twelve work sites in the Minneapolis-St.Paul, Minnesota area. The authors consider the impact of four different price levels (equal price, ten percent cut, twenty-five percent cut, and fifty percent cut) combined with three low-fat promotional strategies (none, low-fat signs, and low-fat signs coupled with messages encouraging low-fat choices at vending machines) over a twelve-month period. They find that price cuts alone are associated with significant increases in low-fat snacks sales as price reductions of ten, twenty-five, and fifty percent resulted in an increase of nine, thirty-nine, and ninety-three percent of low-fat snack sales, respectively. On the other hand, the impact of promotional signs is much weaker.[4]

Another study by French et al. (1997) examines the effects of pricing strategies on sales of fruits and vegetables in an adolescent population at two distinct high schools. Their experiment involves three phases. First, consumption of fruits, carrots, and salad is monitored for an initial baseline period. In the second phase, prices are cut by fifty percent and attractive promotional signs are posted close to these items. Finally, prices are returned to their original level and sales are monitored for another three weeks. Using the combined data for both high schools and work sites, the authors show that, during the second phase where prices are cut, fruit sales increased fourfold, carrot sales increased twofold, and the impact on salad sales is statistically insignificant. Moreover, consumption of fruits and baby carrots in the third phase where prices were returned to their initial level is greater than in phase one.

The above studies have clear implications for public health policy. Lowering prices on healthy food can induce people to eat more fat-free snacks, fruits and vegetables, and healthier meals in restaurants. These previous papers do not, however, connect the price levels directly to the obesity levels. Moreover, they do not perform any rigorous econometric analysis controlling for various other factors that might be important for observed changes in consumption decisions.

[4] Battle Horgen and Brownwell (2002) disentangle the impact of price cuts and promotional health messages by looking at purchases of healthy food items in a restaurant. Their conclusion is that price decreases alone, rather than a combination of price decreases and health messages, were associated with a higher level of increased purchases of some healthy food items as compared with control items. Paradoxically, health messages can have a negative impact on healthy food choice if people assume that foods labeled as healthy have taste badly.

2.2 Econometric Analysis

Chou et al. (2004) extend the previous line of research by considering many potential determinants of body-mass index (BMI) and obesity above and beyond food prices, including the impact of various demographic factors, the number of fast food restaurants, and consumption of cigarettes, and alcohol. Food prices are an aggregate of the price of full service restaurants, the price of fast food restaurants, and the price of food at home. Using an OLS regression of BMI and the probability of being obese, the authors find that the increase in the per capita number of restaurants makes the largest contribution to trends in weight outcomes, followed by the real price of cigarettes, food prices, and the price of alcohol. They find a negative correlation between food prices and weight. The decline in the three food prices considered caused the weight outcomes to rise by an estimated twelve percent. In addition, the authors show that a ten percent decrease in food prices is associated with a 0.7 percentage point increase in the percentage obese.

Schroeter et al. (2008) develop a static theoretical model of food choices to assess the impact of government policies on people's weight. Imposing a tax on high-calorie foods undoubtedly reduces the consumption of such good. However, the impact of such a tax on people's weight critically depends on the relationship between high-calorie and low-calorie food. The authors find that, when high-calorie and low-calorie food are complements, a tax on high-calorie food lead to a weight decrease. However, when high-calorie and low-calorie food are substitutes, the effect of a tax on high-calorie food on people's weight is ambiguous.

Finally, Lakdawalla et al. (2005) study the relationship between the long-run growth in weight over time and technological change, which has simultaneously lowered the cost of calories and raised the cost of physical activity. First, the farming technology developed over the last century relies far less on human power and more on machinery. This mechanization has lowered the cost of production and hence the price of food. Second, technological improvements made work less intensive and due to this decline in physical activity people gained weight. Lakdawalla and Philipson (2002) look at the effect of food prices on calorie consumption using price data for different US states. Differences in the tax code across US states, specifically whether food are exempt from sales taxes or not, create exogenous differences in food prices. Using a three stage least squares regression, the authors find that about forty percent of the recent growth in weight is due to agricultural innovation that has lowered food prices. The rest is due to the factors such as declining physical activity from technological changes in home and market production.[5]

It is difficult to derive policy implications based on the above empirical studies because estimates of the impact of changes in food price on people's eating decisions and weight vary greatly. The estimates of Chou et al. (2004) imply a more modest impact of prices, while the estimates Lakdawalla and Philipson (2002) are larger.

3 Data

Between 1977 and 2005, Americans gained on average twenty-two pounds, as the average weight increased by fourteen percent from 155 in 1977 to 177 in 2005. Over the same period of time, total daily calories increased by twenty-three percent from 2180 to 2681, according to the data constructed by the U.S. Department of Agriculture (USDA).[6] The positive relationship that exists between prevalence of obesity and calorie intake follows from simple dieting accounting principles. In order to maintain a healthy BMI, calorie intake must be balanced with calories expenditures. Everything else equal, if calories intake goes up while calorie expenditures remain roughly constant or declines over time, a person's weight increases (Cutler et al., 2003 or Philipson and Posner, 1999).

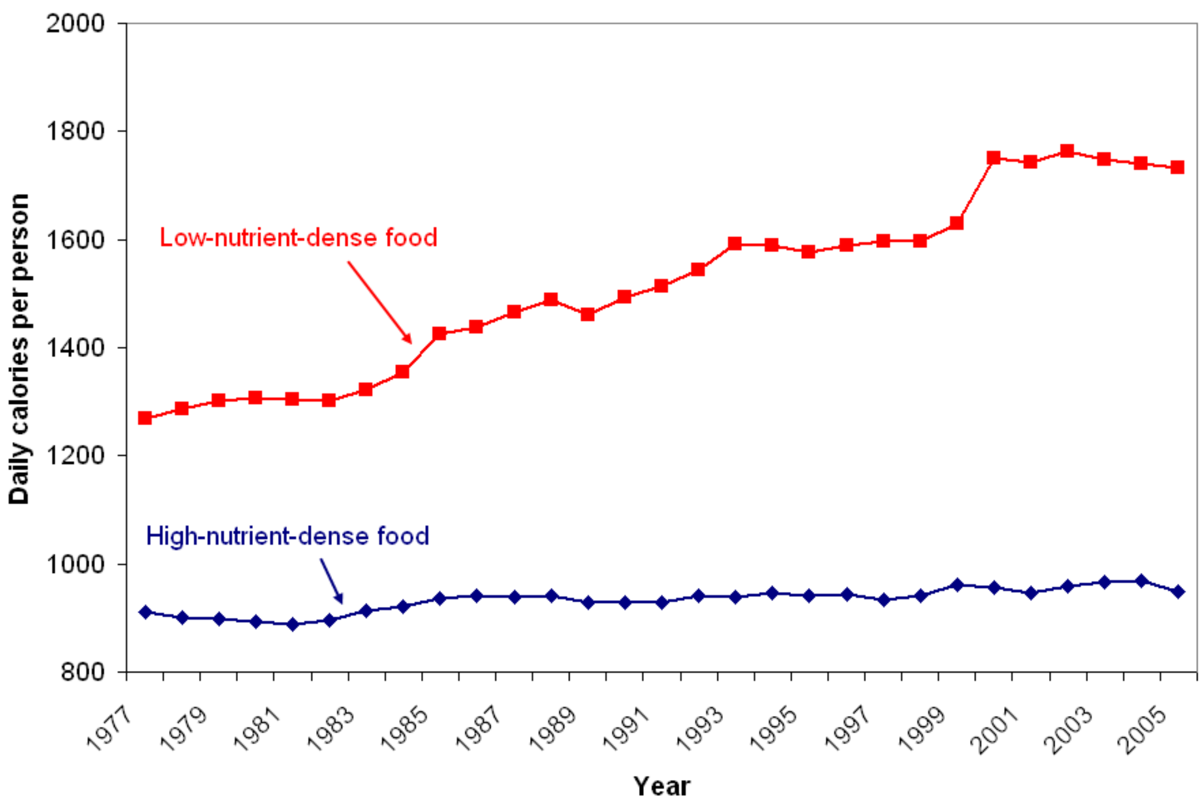
The increase in total daily calories is not uniform across food categories, however. To

[5]Cutler et al. (2003) show that increased caloric intake is far more important than reduced caloric expenditure in explaining recent increases in obesity in the US.

[6]Following the U.S. Department of Agriculture (USDA) classification, daily calories intake is calculated as the sum of daily calories consumption from six different food categories: (i) meat, eggs, and nuts, (ii) dairy, (iii) fruits and vegetables, (iv) flour and cereal products, (v) added fats, and (vi) added sugars.

show this point, we create two distinct food categories that we call "high-nutrient-(dense)" and "low-nutrient-(dense)" food. The high-nutrient food group consists of calories intake from fruits and vegetables, dairy, meat, eggs, and nuts. The low-nutrient food group consists of calories intake from added sugars, added fats, and flour and cereal products. In Figure 1, we see that daily calorie intake from the high-nutrient food category has remained roughly constant (it increased slightly by thirty-five calories per day or by four percent), while daily calorie consumption of low-nutrient food has increased by thirty-seven percent from 1268 in 1977 to 1733 in 2005.

Fig. 1: Daily Calorie Intake over Time for High-Nutrient and Low-Nutrient Food



Source: USDA/Economic Research Service. Data last updated Feb. 15, 2007.

Next, we introduce a new method for calculating per calorie food prices. We construct an aggregate time series for the average price per calorie of high-nutrient and low-nutrient food category. A usual place to obtain the information on changes in prices is at the Bureau of Labor Statistics (BLS). However, BLS price indices are normalized to one hundred. As a result, we can only calculate the percentage change in price for each of the BLS food category and we cannot infer the relative price between high-nutrient and low-nutrient food. To circumvent these difficulties, we bring additional data on household's expenditures share from BLS, household consumption total expenditures from the Bureau of Economic Analysis (BEA), and the above mentioned USDA data on calorie intake (for more information on the USDA and BLS data, please see the Appendix). For each year t between 1977 and 2005, we calculate the price of high-nutrient food per calorie, $p_{H,t}$, and low-nutrient food per calorie, $p_{L,t}$, as follows:

$$p_{H,t} = \frac{\alpha_{H,t} I_t}{\text{Calories}_{H,t}}, \quad p_{L,t} = \frac{\alpha_{L,t} I_t}{\text{Calories}_{L,t}} \tag{1}$$

where $\alpha_{H,t}$ and $\alpha_{L,t}$ denote the expenditure share on high- and low-nutrient food, respectively, I_t represents real income in period t, and $\text{Calories}_{H,t}$ and $\text{Calories}_{L,t}$ are calories consumed from high- and low-nutrient food in period t.

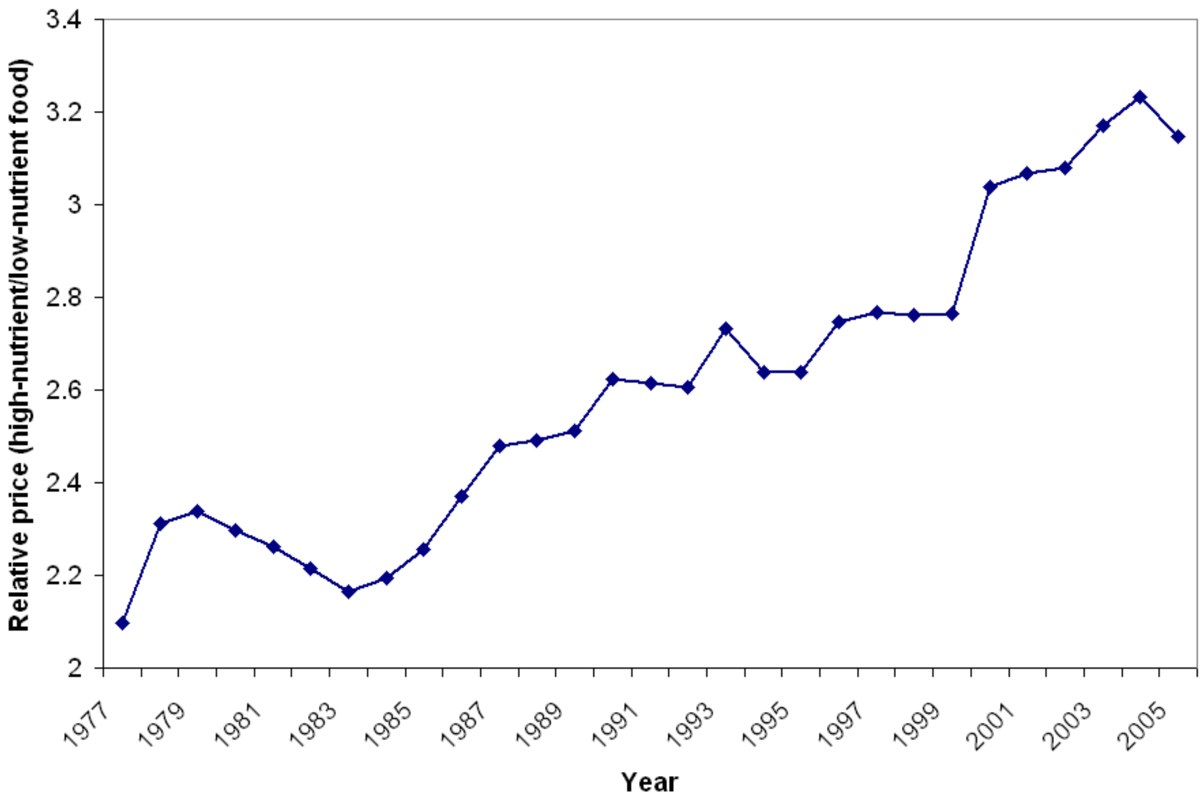
Expenditure shares on high- and low-nutrient food are equal to:

$$\begin{aligned} \alpha_{H,t} &= \alpha_{FV,t} + \alpha_{D,t} + \alpha_{ME,t} \\ \alpha_{L,t} &= \alpha_{O,t} + \alpha_{S,t} + \alpha_{C,t} + \alpha_{NB,t} \end{aligned} \tag{2}$$

where $\alpha_{FV,t}$, $\alpha_{D,t}$, and $\alpha_{ME,t}$ denote the expenditure share on fruits and vegetables, dairy, and meats, poultry, and egg, respectively, and $\alpha_{O,t}$, $\alpha_{S,t}$, $\alpha_{C,t}$, and $\alpha_{NB,t}$ denote expenditure share on oil and fats, sugar and sweets, cereal and bakery products, and non-alcoholic beverages, respectively.

In Figure 2, we present changes in the real price of high- and low-nutrient food between 1977 and 2005. First note that, per calorie, high-nutrient food is always more expensive than low-nutrient food. In fact, the ratio between high- and low-nutrient food widens from 2.1 in 1977 to 3.15 in 2005, an increase of fifty percent. Second, the real price of high-nutrient

Fig. 2: Changes in Relative Price Over Time



food has increased by twenty-five percent, while the price of low-nutrient food declined by sixteen percent.

4 An Infinite-Horizon Model of Eating Decisions

In this section, we propose a stochastic dynamic optimization model in the spirit of Levy (2002) to study the impact of changes in relative food prices on calorie consumption and weight. Time is discrete and infinite, $t = 1, 2, ...$ In each period, agents decide how much to consume of calories from high-nutrient food, h_t, calories from low-nutrient food, l_t, and non-food consumption, c_t^{nf}. Food consumption is aggregated according to a constant elasticity of substitution (CES) function:

$$c_t^f = (\eta h_t^\rho + (1-\eta) l_t^\rho)^{\frac{1}{\rho}} \tag{3}$$

with $\eta \in (0,1)$, $\rho \in (-\infty, 1]$, and c_t^f denotes a composite of calories consumed. Note that high- and low-nutrient food are perfect substitutes, Cobb-Douglas, or perfect complements when the parameter ρ is equal to one, zero, or minus infinity, respectively.

Contemporaneous preferences are bounded from below and given by:

$$U(c_t^f, c_t^{nf}) = \begin{cases} c_t^{nf} + \mu \log(c_t^f) & \text{if } c_t^f \geq \bar{c} \\ \bar{U} & \text{if } c_t^f < \bar{c} \end{cases} \tag{4}$$

where $\mu > 0$ and $\bar{c} > 0$. We assume that $\bar{U} \leq \mu \log(\bar{c})$ so that it is never optimal for people to eat less than $\bar{c}$. A possible interpretation for $\bar{c}$ is that it represents a food subsistence level and that people die and receive utility $\bar{U}$ if they eat less than $\bar{c}$ in any period. On the other hand, when food consumption is greater than the subsistence level, preferences are quasi-linear which implies that changes in real income have no effect on food consumption.

At the beginning of each period, a "special" coin is tossed which determines whether the representative agent survives the period or dies. We denote by $\pi(W_t)$ the time-invariant conditional probability that the representative agent with weight W_t makes it to the next time period provided that she is alive at the beginning of the period. We assume that the survival probability is inverted U-shape and that there is a best weight, $\bar{W}$, at which the conditional survival probability is at its maximum and equal to one. Death is an absorbing state and the representative agent receives utility $\bar{U}$ forever if she dies. The expected utility discounted to period one is equal to:

$$\sum_{t=1}^{+\infty} \beta^{t-1} (\Pi_{s=1}^{t-1} \pi(W_s))(\pi(W_t) U(c_t^f, c_t^{nf}) + (1 - \pi(W_t))\bar{U}) \tag{5}$$

where the parameter $\beta \in (0,1)$ is the pure time discount factor. Note that the representative agent can die in two very different ways. In the short-run, she dies if she eats less than the subsistence level, $\bar{c}$. In the long-run, the probability of death increases when the distance between her weight and the best weight, $\bar{W}$, becomes larger.

The budget constraint of the representative agent is given by:

$$c_t^{nf} + p_{ht} h_t + p_{lt} l_t = I_t \tag{6}$$

where we normalized the price of non-food to one, p_{ht} and p_{lt} are the real price of high- and low-nutrient food, respectively, and agents are endowed with real income I_t.

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

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

where $\lambda > 0$ is a parameter that converts calorie consumption into weight gain and $\delta_w \in (0, 1)$ denotes the weight depreciation rate.

For any given sequence of prices and income, $\{p_{ht}, p_{lt}, I_t\}_{t\geq 1}$, and an initial weight, W_1, the representative agent chooses an optimal sequence of high- and low-nutrient food, $\{h_t, l_t\}_{t\geq 1}$, to maximize the expected utility discounted to period one in equation (5) subject to the aggregation equation (3), the budget constraint (6), the weight law of motion (7), and non-negativity constraints for calorie and non-food consumption.

We substitute non-food consumption from the budget constraint into the objective constraint and take first-order conditions with respect to h_t and l_t. When the solution is interior, we have:

$$\begin{aligned}
&[h_t]: \quad p_{ht} - \frac{\mu\eta h_t^{\rho-1}}{\eta h_t^{\rho} + (1-\eta) l_t^{\rho}} = \lambda\beta\pi'(W_{t+1})\times \\
&(\frac{\mu}{\rho}\log(\eta h_{t+1}^{\rho} + (1-\eta) l_{t+1}^{\rho}) + I_{t+1} - p_{ht+1}h_{t+1} - p_{lt+1}l_{t+1} - \bar{U}) \\
&[l_t]: \quad p_{lt} - \frac{\mu(1-\eta) l_t^{\rho-1}}{\eta h_t^{\rho} + (1-\eta) l_t^{\rho}} = \lambda\beta\pi'(W_{t+1})\times \\
&(\frac{\mu}{\rho}\log(\eta h_{t+1}^{\rho} + (1-\eta) l_{t+1}^{\rho}) + I_{t+1} - p_{ht+1}h_{t+1} - p_{lt+1}l_{t+1} - \bar{U})
\end{aligned} \tag{8}$$

We analyze the previous system of equations in the case of a stationary equilibrium where all prices and quantities are constant over time. That is, $h_t = h^*$, $l_t = l^*$, $W_t = W^*$, $p_{ht} = p_h$, $p_{lt} = p_l$, and $I_t = I$ for every t. The steady-state weight is equal to $W^* = \frac{\lambda(h^*+l^*)}{\delta_w}$.

As a result, the first-order conditions evaluated at the steady state are given by:

$$p_h - \frac{\mu\eta h^{*\rho-1}}{\eta h^{*\rho} + (1-\eta)l^{*\rho}} = p_l - \frac{\mu(1-\eta)l^{*\rho-1}}{\eta h^{*\rho} + (1-\eta)l^{*\rho}}$$

$$p_h - \frac{\mu\eta h^{*\rho-1}}{\eta h^{*\rho} + (1-\eta)l^{*\rho}} = \lambda\beta\pi'(\frac{\lambda(h^* + l^*)}{\delta_w})(\frac{\mu}{\rho}\log(\eta h^{*\rho} + (1-\eta)l^{*\rho}) + I - p_h h^* - p_l l^* - \bar{U}) \tag{9}$$

In the next section, we calibrate the model to reflect the average weight and calorie consumption of Americans as well as food prices in 1977, assuming that the economy is in a steady-state.

5 Calibration

First, we know from data on calorie consumption that daily calorie intake in 1977 of high- and low-nutrient food is equal to $h^{*,1977} = 912$ and $l^{*,1977} = 1268$, respectively.

Second, we set the pure discount factor equal to $\beta = 0.96$ per year (or $\beta = 0.998$ per day) as this value for the time discount factor is commonly used in infinite horizon macroeconomic models.

Third, we calibrate the parameters in the weight law of motion. The average weight of Americans in 1977 is equal to 155 pounds. As a result, we fix $W^{*,1977} = 155$. We assume that agents would loose one percent of their weight if they did not eat for one day, which implies that the daily depreciation rate is equal to $\delta_w = 0.01$. Finally, the parameter λ is determined by the following equation:

$$\lambda = \frac{\delta_w W^{*,1977}}{h^* + l^*} \tag{10}$$

As a result, $\lambda = 7.12e^{-4}$. To put things into perspective, our calibrated value of λ implies that the steady state weight increases by 7.12 pounds when agents consume an extra 100 calories per day. This number tends to be on the lower side of estimates from health experts who estimate the weight gains from consuming an extra 100 calories per day is on average ten pounds per year. However, this estimate does not take into account physical activity, gender, or age.

Fourth, we calibrate prices of food and income using the methodology explained in the data section and summarized in equation (1). Using data from BEA, the daily real per-capita income is equal to $I^{1977} = \$25.26$. Moreover, BLS reports the share of income spent on food items. Since we know calorie intake for high- and low-nutrient food, we calculate the price per calorie of high-nutrient food and low-nutrient food by dividing the dollar amount spent on each type of food by calorie. We find that the price of a calorie of high- and low-nutrient food in 1977 is equal to $p_h^{1977} = 1.28^{-3}$ and $p_l^{1977} = 6.12e^{-4}$, respectively.

Fifth, we calibrate the conditional probability of survival. We assume that this probability follows the following function form:

$$\pi(W_t) = e^{-a(W_t - \bar{W})^2} \tag{11}$$

In the above expression, $\bar{W}$ denotes the best weight at which the conditional survival probability is at its maximum and equal to one and a is a positive parameter. Note that, because of the squared term, the survival probability declines whenever the representative agent weight is not equal to $\bar{W}$. We assume that the best weight for the representative agent is equal to the average weight of Americans in 1977. That is, $\bar{W} = 155$. We now calibrate the parameter a. According to research in the medical field, the likelihood of death doubles when person's BMI increases from 25 to 35 (Allison et al., 1999). Changes in weight are related to changes in BMI by the following formula:

$$\Delta BMI = 703 \frac{\Delta W}{\text{height}^2} \tag{12}$$

Since the average height of Americans in 1977 is equal to 65 inches, the increase in BMI represents a change in weight equal to $\Delta W = \frac{10 \times 65^2}{703} = 60$ pounds. As a result, the parameter a is given by:

$$a = \frac{\log(2)}{3600} \tag{13}$$

Tab. 1: Calibrated Parameters

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
$h^{*,1977}$	912	I^{1977}	\$25.26	λ	$7.12e^{-4}$	a	$\frac{\log(2)}{3600}$
$l^{*,1977}$	1268	$W^{*,1977}$	155	$\bar{W}$	155	μ	1.9434
p_h^{1977}	1.28^{-3}	β	0.998	$\bar{c}$	1	ρ	0
p_l^{1977}	$6.12e^{-4}$	δ_w	0.01	$\bar{U}$	0	η	0.6

Sixth, we fix the subsistence level and utility from death to $\bar{c} = 1$ and $\bar{U} = 0$, respectively.

Finally, we need to determine the value of the preference parameters, μ, η, and ρ. Since we have no direct evidence about whether calories from high- and low-nutrient food are either complement or substitute, we start with the agnostic Cobb-Douglas case where the elasticity of substitution is equal to one, i.e. $\rho = 0$. The two remaining parameters, μ and η are then determined by the solution to the following equation:

$$p_h - \frac{\mu\eta}{h^{*,1977}} = p_l - \frac{\mu(1-\eta)}{l^{*,1977}} = 0 \tag{14}$$

Solving these equations, we find that $\mu = 1.9434$ and $\eta = 0.6$. We summarize the calibrated parameter values in Table 1.

6 Numerical Experiments

In this section, we use our calibrated model to look at the impact of changes in price of high- and low-nutrient food taken one at a time and then altogether. We also derive modeling implications from comparative statics analysis.

6.1 Changes in Prices

Qualitatively, the three following effects are at work. First, changes in the relative price of food imply a reallocation of calorie consumption away from high-nutrient food to low-nutrient food (substitution effect). Second, since agent's preferences are quasi-linear, there is no static income effect. Finally, agents choose total calorie consumption to keep the steady state weight as close as possible to the best weight because it increases their survival probability (dynamic effect).

Between 1977 and 2005, the price of high-nutrient food increased by twenty-five percent from $\$1.28e^{-3}$ in 1977 to $\$1.61e^{-3}$ in 2005. Our first experiment consists of changing the price of high-nutrient food, while keeping the price of low-nutrient food constant to its 1977 value. We find that calorie consumption from high-nutrient food declines by about eighteen percent, while calorie consumption from low-nutrient food increases by eight percent (see Table 2). Overall, total calorie consumption declines which implies a weight reduction of slightly less than five pound, or -3.03 percent.

Between 1977 and 2005, the price of low-nutrient food declined by sixteen percent from $\$6.12e^{-4}$ per calorie in 1977 to $\$5.11e^{-4}$ in 2005. Our next experiment consists of changing the price of low-nutrient food, while keeping the price of high-nutrient food constant to its 1977 value. Calorie consumption from low-nutrient food increases by about nine percent, while calorie consumption from high-nutrient food decreases by four percent (see Table 2). Overall, we find that total calorie consumption increases which implies a weight gain of slightly more than five pound, or 3.43 percent.

Finally, we look at the impact of changes in food prices taken altogether on calorie consumption of high- and low-nutrient food as well as weight. In Table 2, we see that calorie consumption of high-nutrient food declines by roughly twenty-one percent, while calorie consumption of low-nutrient food increases by sixteen and a half percent. Overall, total calorie consumption increases which implies a net gain of one pound for the steady state weight. The increase in weight and calories predicted by the model comes short of the twenty-two pounds gain that is observed in the data. The reason is that increases in calorie consumption of low-nutrient food are offset by decreases in calorie consumption of high-nutrient food. As a result, increases in weight are very modest.

Tab. 2: Percentage Change in Calorie Consumption and Weight - Model Predictions

	$\Delta p_h(\uparrow)$	$\Delta p_l(\downarrow)$	All
Δh^*	-18.31%	-4.06%	-21.27%
Δl^*	7.89	8.61	16.56
ΔW^*	-3.03	3.43	0.65

Our results shed light on the previous findings from the literature. On the one hand, changes in prices of either high- or low-nutrient food taken one at a time have a great impact on people's eating choices, which is in line with findings of the experimental economics literature (French et al., 2001). On the other hand, changes in prices of high- and low-nutrient food taken altogether have offsetting effects on people's eating habits and thus have little impact on people's weight. This result is consistent with findings of the empirical economics literature (Chou et al., 2004). In the next section, we conduct a comparative statics exercise to assess how much of our results comes from the assumptions we made about the relationship between high- and low-nutrient food (substitutes versus complements) as well as the survival probability.

6.2 Comparative Statics

6.2.1 Changes in Elasticity of Substitution

In our baseline calibration, where the elasticity of substitution between calorie consumption from high- and low-nutrient food is equal to one (Cobb-Douglas function), changes in prices have little quantitative impact on people's weight. In this section, we perform our experiments one more time for two different values of the elasticity of substitution. We consider the case where $\rho = -5$ (high- and low-nutrient food are complements) as well as the case where $\rho = +\frac{1}{2}$ (high- and low-nutrient food are substitutes). We summarize the results of our experiments in Table 3.

Tab. 3: Percentage Change in Calorie Consumption and Weight

A. Complement Case, $\rho = -5$

	$\Delta p_h(\uparrow)$	$\Delta p_l(\downarrow)$	All
Δh^*	-8%	1.21%	-5.81%
Δl^*	-3.08	3.55	1.18
ΔW^*	-5.16	2.58	-1.94

B. Substitutes Case, $\rho = \frac{1}{2}$

	$\Delta p_h(\uparrow)$	$\Delta p_l(\downarrow)$	All
Δh^*	-27.74%	-9%	-33.88%
Δl^*	18.14	13.09	23.9
ΔW^*	-1.03	4.13	-0.39

We recalibrate the parameters η and μ to account for the change in the elasticity of substitution. The calibrated parameters η and μ are given by the following expression:

$$\frac{\eta}{1-\eta} = \frac{p_h}{p_l}\left(\frac{l^{*,1977}}{h^{*,1977}}\right)^{\rho-1}$$
$$\mu = p_h h^{*,1977}\left(1 + \frac{1-\eta}{\eta}\left(\frac{l^{*,1977}}{h^{*,1977}}\right)^{\rho}\right) \tag{15}$$

When goods are complements, $\rho = -5$, we find that $\eta = 0.2445$ and $\mu = 1.9434$. When goods are substitutes, $\rho = +\frac{1}{2}$, the parameters are equal to $\eta = 0.6395$ and $\mu = 1.9434$.

Changes in the elasticity of substitution have a great impact on people's eating habits. For example, when goods are complements, an increase in the price of high-nutrient food results in a decrease of calorie consumption of both high- and low-nutrient food. Similarly, calorie consumption of both high- and low-nutrient food increases following a decrease in the price of low-nutrient food. Overall, changes in prices taken altogether result in a decrease of the steady state weight, which is consistent with the results in Schroeter et al. (2008). When high- and low-nutrient food are substitutes, the impact of changes in prices is exacerbated compared to the Cobb-Douglas case. For example, following an increase in the price of high-nutrient food, changes in calories consumption of high- and low-nutrient food are equal to minus twenty-eight and plus eighteen percent, respectively, compared to minus eighteen and plus eight percent for the Cobb-Douglas case. Given the sensitivity of our results to the elasticity of substitution, we believe that more empirical work is needed to shed light on the relationship between high- and low-nutrient food.

6.2.2 Changes in the Survival Probability

In this section, we perform our experiments of changes in price for different values of the parameter a which affects the impact of weight on the survival probability. Since the impact of changes in prices on weight and calorie consumption is greater the lower the value for a, we only report the results of our experiments when a is equal to zero (see Table 4).

When a is equal to zero, agents solve a sequence of static maximization problems and the cross-price elasticity is equal to zero since the relationship between high- and low-nutrient food is Cobb-Douglas. As a result, increases in the price of high-nutrient food have no impact on calorie consumption of low-nutrient food, while calorie consumption of high-nutrient food declines by twenty-one percent (see Table 4). Similarly, decreases in the price of low-nutrient food have no impact on calorie consumption of high-nutrient food, while calorie consumption of low-nutrient food increases by twenty percent. Overall, when changes in prices are taken altogether, the agent's steady state weight increases by two and half percent. This represents a greater impact compared to our baseline calibration but still falls short of the increase in weight that is observed in the data.

Tab. 4: Percentage Change in Calorie Consumption and Weight - Static Model

a = 0	$\Delta p_h(\uparrow)$	$\Delta p_l(\downarrow)$	All
Δh^*	-20.61%	0	-20.61%
Δl^*	0	19.64	19.64
ΔW^*	-9.03	11.61	2.58

7 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 1977 and 2005. After a careful calibration of the model using available evidence from medical research, we found that changes in food prices altogether account for less than five percent of the increase in people's weight. This is because increases in calorie consumption of low-nutrient food are offset by decreases in calorie consumption of high-nutrient food as the price of high- and low-nutrient food move in opposite directions. As a result, increases in weight are very modest.

We see two important avenues for future research. First, since our results are very sensitive to the elasticity of substitution between high- and low-nutrient food, we believe that more empirical work is needed to determine whether high- and low-nutrient food are complements or substitutes. Second, we examined the effect of prices in a model where agents are fully rational. Evidence from behavioral and neuroeconomics show that eating decisions are complex and heavily influenced by environmental factors (Read and van Leeuwen (1998) or McClure, Ericson, Laibson, Lowenstein, and Cohen (2007)). For example, people make very different food choices when their decisions are made "on the spot" or in advance (Rogers, Milkman, and Bazerman 2007). This suggests that more theoretical work is needed to understand people's eating decisions, including assessing the importance of time-inconsistent preferences.

8 The Appendix

8.1 Food Categories

In this section, we compare the USDA and the BLS food categories. By looking at Table 5, we can see that these two lists are not identically the same. In addition, the items in each specific category are also slightly different. In the case of fruits and vegetables, dairy, and meats the two data set are very similar and contain similar items. However, the USDA series called "Added sugars", "Added fats", and "Flour and cereal products" are quiet different from the BLS series called "Sugars and sweets", "Fats and oils", and "Cereals and bakery products". The major difference is because the USDA food groups include finished products as well as ingredients for other food.

The series called "Added fats" by USDA and "Fats and oils" by the Bureau of Labor Statistics (BLS) have items in common such as butter, margarine, salad dressings, and cooking oils. However, the USDA also includes other fats such as shortening and other edible fats and oils that may be added in other processed foods like bread, muffins, and cookies. As a result, added fats under USDA reflects both direct use and indirect ingredient use for fats and oils in other food products.

Next, the series called "Added sugars" by USDA and "Sugar and sweets" by BLS both include sugar like refined cane and beet sugar. However, the BLS series also includes candy and chewing gum, artificial sweeteners, and other sweets. Moreover, the USDA series includes other sweeteners like corn sweeteners, HFCS, and other edible syrups that are regularly added to other processed foods like bread, biscuits, rolls, muffins, cookies, fresh cakes, cupcakes, etc. in addition to nonalcoholic beverages.

Finally, the series labeled as "Flour and cereal products" at USDA and the called "Cereal and bakery products" by BLS both include items such as flour and rice. However, the BLS series include more processed products rather than simply the ingredients for bakery products. The BLS series includes items such as pasta, cereals, breads, biscuits, rolls,

Tab. 5: Food Categories

USDA food categories	BLS food categories
Fruits	Fruits and vegetables
Vegetables	
Dairy	Dairy and related products
Meat, eggs, and nuts	Meats, poultry, and fish
Added sugars	Sugars and sweets
Added fats	Fats and oils
Flour and cereal products	Cereals and bakery products
	Other prepared foods
	Nonalcoholic beverages and beverage material

muffins, cookies, fresh cakes, cupcakes, etc. The USDA series on the other hand includes wheat flour, rye flour, oat products, and barely products.

Now, in our paper we construct two food categories: The "good" food group consists of fruits and vegetables, dairy, meat, eggs, and nuts. The "bad" food group consists of added sugars, added fats, and flour and cereal products.

By lumping together the USDA categories Fruits, Vegetables, Dairy, and Meat, eggs, and nuts and by lumping together the BLS categories Fruits and vegetables, Dairy and related products, and Meats, poultry, and fish we do match the calories from USDA data set to prices from the BLS data set. Similarly, by lumping together the USDA categories "Added sugars", "Added fats", and "Flour and cereal products" and by lumping together the BLS categories "Sugars and sweets", "Fats and oils", "Cereals and bakery products", "Other prepared foods" and "Nonalcoholic beverages and beverage material" we also match the calories from USDA data set to prices from the BLS data set.

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