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Association between Total Diet Cost and Diet Quality Is Limited

Andrea Carlson, Diansheng Dong, and Mark Lino

There is a common perception that it costs more to eat a healthy diet than a less healthy one. We derive a panel data model that accounts for unobserved specific individual effects to estimate the relationship between diet quality and total daily food expenditure. Since total daily diet cost and diet quality are both calculated from the foods chosen in our data, we account for the fact that there is an endogenous relationship between diet quality and cost. We find that while total daily food expenditure is statistically significant in relation to diet quality, the degree of association is very small.

Key words: cost of food, diet quality, HEI-2005, NHANES, random-effects model

Introduction

There is a long-standing policy debate on whether healthy foods cost more than less healthy ones. Researchers have established that eating a healthy diet is possible even on a minimal-cost food budget (Carlson and Stewart, 2011; Stewart et al., 2011b; Carlson, Lino, and Fungwe, 2007; Carlson et al., 2007). In case study experiments, researchers have also worked directly with households to change food purchase habits over time and achieve a healthier diet. When families switch to a low-fat diet (Mitchell et al., 2000) or switch to an overall healthy diet (Raynor et al., 2002), their food budgets can actually be lower than they were before the transition. However, some studies reason that because obesity and poor diet quality occur at higher levels in low-income populations, it may be the case that healthy diets are more expensive than less healthy ones (Aggarwal, Monsivais, and Drewnowski, 2012; Townsend et al., 2009; Drewnowski, 2010a,b; Drewnowski and Barratt-Fornell, 2004). If there is a significant relationship between food expenditure and the healthfulness of the diet, then the obesity problem could be reduced by simply spending more money on food. Other researchers find a range of differences depending on how food prices are measured (Carlson and Frazão, 2012; Stewart et al., 2011a,b) or what time period and geographic region are covered (Todd, Leibtag, and Penberthy, 2011).

These diverse findings suggest that the solution to the obesity epidemic is more complex than a simple cost barrier. However, data that contain both actual expenditure and actual consumption—the food eaten by individuals, not the food purchased—is usually not available. To our knowledge there are no large-scale studies that combine both total food expenditures and the healthfulness of the foods chosen by the individual in order to assess whether those who choose a healthy diet actually spend more on food than those who do not.

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Researchers have used a variety of methods to proxy one or both of these measures in the data. The most common is to use food expenditure data for key food categories such as vegetables and fruits and snack foods or foods high in added sugars to proxy for food eaten. Beatty (2008) uses the 1996 Canadian Family Food Expenditure Survey to look at the relationship between the number of shopping trips, total food expenditure, and the nutrient content or food group of purchased foods over a two-week period. Their study concludes that purchases of foods high in fat increase as total expenditure goes up, but foods high in carbohydrates and fruit and vegetable purchases decrease. Using data from the 2000 Consumer Expenditure Survey, Stewart, Blisard, and Jolliffe (2003) find that while total expenditures on vegetables and fruits and sweets and snacks are greater for higher income individuals, the ratio of expenditures is about the same as for lower income households. As Stewart, Blisard, and Jolliffe note, the limitation of these studies is that the actual quantities of fruits, vegetables, sweets, or snack foods purchased or actually consumed is unknown. Since there is a wide variation in the prices of fruits and vegetables (Carlson and Frazão, 2012; Stewart et al., 2011a), we cannot conclude from these studies whether income or total expenditure is related to the actual consumption of food. Hiza et al. (2013) find that there is no statistical difference in fruit consumption between low- and high-income individuals, but higher income individuals do consume more vegetables. Regardless of income, average vegetable consumption is far below recommended levels. Carlson and Stewart (2011) demonstrate the types and quantities of fruits and vegetables that households could purchase to meet the fruit and vegetable recommendations listed at www.choosemyplate.gov and spend a food budget equivalent to the maximum benefit of the Supplemental Nutrition Assistance Program (SNAP).

We found one study that ties a measure of food consumption and diet quality to energy-adjusted food expenditures. Bernstein et al. (2010) find that while female nurses in a long-term study who eat healthier and have less energy-dense diets do spend more (per calorie) on food, large improvements in diet quality can be made at the same calorie-adjusted food expenditure. In this study, food cost and diet quality are based on a detailed food frequency[1] measure rather than a set of twenty-four-hour dietary recalls. In order to estimate diet cost and address the problem of not knowing the actual amounts of food consumed, Bernstein et al. assumed that each participant only consumed 1,800 calories; in other words, they used an energy-adjusted total cost rather than an actual total cost.

When applied to studies of economics and cost, the energy adjustment is potentially misleading because food energy does not measure either an amount of food or satiety (for a detailed discussion of food price metrics see Carlson and Frazão, 2012). In estimating the cost of a healthy diet, we need to be concerned about both the amount of food energy (measured in calories) consumed and the overall composition or diet quality of what is consumed. Individuals who need more food energy to support their larger body size (both height and weight) will need to eat more calories than a smaller person. If the large and small people both eat the same foods, the larger person will need to spend more money to support his or her larger size. If they do not eat the same foods—say one eats less energy dense foods and one consumes more energy dense foods—then we cannot say who will spend more. While the Bernstein study has its strengths, it still lacks a measure of cost that consumers actually use when making decisions about which foods to purchase and eat.

In order to assess the relationship between total daily cost and overall diet quality, the measure of cost and measure of diet quality must work together to cover the quantity of food consumed, total energy consumed, and diet composition. The data should reflect actual decisions made by consumers in the United States, and the cost should be measured in a way that reflects reality. Any examination of the relationship between diet cost and healthfulness must also control for confounding factors that

[1] There are multiple ways of collecting data on what individuals consume. The two most common are food frequency and dietary recall. In the food frequency method, respondents are asked how often they consume certain foods such as broccoli or food groups such as vegetables. Information on the quantity consumed is not collected, and it would not be possible to capture all foods that a respondent eats. In the dietary recall method, the study participant is asked a series of questions to report all the foods eaten over a twenty-four-hour period; amounts consumed are also collected. Specific questions are included to encourage participants to report forgotten foods such as candy from an officemate's candy jar and foods and beverages consumed while doing something else such as sitting at a desk or driving.

have been shown to have a relationship with diet quality, such as demographic factors (Bhargava and Hays, 2004; Hiza et al., 2013; Huston and Finke, 2003; Kinsey, 1994; Savoca et al., 2009; Schroeter, Anders, and Carlson, 2013; Variyam et al., 1998; Variyam, Blaylock, and Smallwood, 1996) and health behaviors and indicators—such as exercise habits, smoking, and being overweight—that may indicate the value the individual places on health or their discount rate for future health (Huston and Finke, 2003; Ma, Betts, and Hampl, 2000; Schroeter, Anders, and Carlson, 2013).

In this paper, we estimate a model that tests the relationship between diet quality and diet cost to individuals using a two-day individual survey dataset. Individuals' diet quality, as measured by their HEI-2005 scores, is derived from household utility maximization as a function of their total daily diet cost, food behaviors, health behaviors and indicators, and demographic characteristics. To our knowledge, this is the first study with national data that examines the relationship between total expenditure and diet quality. We use total diet cost and diet expenditure somewhat interchangeably. In using both terms, we mean the sum of the estimated prices of each food the individuals ate. We do not include factors that might be included in an economic cost, such as time or natural resource use. The figure includes the price of foods that the individual may not have actually purchased and does not include the price of foods the individual may have purchased for others to eat. For example, if the participant had dinner at a friend's house, the meal is priced in the participant's food expenditure. If the participant hosts a dinner party, only the cost of the foods he or she actually ate is included, not the cost of the food served to guests. Ultimately, we find a limited relationship between total daily expenditure and diet quality.

Methods

Model

To establish the relationship between the food quality consumed by individuals and total food expenditure, we start from the household production model originally developed by Becker (1965), then apply the characteristic or attribute demand model developed by Lancaster (1966) and incorporated into a health mode by several authors (Behrman et al., 1988; Akin et al., 1992; Rosenzweig and Schultz, 1983). This approach has frequently been used to estimate the demand for food and nutrition (for example, Cawley, 2004; Grossman, 1972; Variyam et al., 1998; Carlson and Senauer, 2003). In this framework, the household member is assumed to derive utility from household produced goods such as health, using goods purchased in the market and their skills, knowledge and other endowments. To study a household's health produced from foods and other health inputs, we assume that the household food and health utility (U) is separable from other commodities and the household member (individual) wishes to maximize it by choosing $\boldsymbol{q}$:

$$\max_{\boldsymbol{q}} U(\boldsymbol{q}, H), \tag{1}$$

where U is quasiconcave (the Hessian of U is negative definite), $\boldsymbol{q}$ is a vector of foods purchased in the market, and H is the health status generated from the nutrition intakes of food $\boldsymbol{q}$ and other health inputs (e.g., not smoking, exercise, taking vitamin supplements, or using medical services). H has the following production function:

$$H = h(\boldsymbol{q}, \boldsymbol{w} | \boldsymbol{C}, \boldsymbol{v}), \tag{2}$$

where $\boldsymbol{w}$ is a vector of other health inputs (nonfood), which do not augment the utility other than through their effects on H. The efficiency of producing health from $\boldsymbol{q}$ and $\boldsymbol{w}$ is conditional on $\boldsymbol{C}$, the household member's characteristics such as age and education that measure the ability of the individual to produce health, and $\boldsymbol{v}$, the exogenous health endowment such as generic traits (e.g., predisposition to diabetes) that are beyond the individual's control. Individuals choose $\boldsymbol{q}$ to maximize U subject to the constraints of income and the individual's ability to produce H from $\boldsymbol{q}$ and $\boldsymbol{w}$ (health production). By maximizing equation (1) subject to equation (2) and adopting the strategy used by Variyam et al. (1998) to assume that the individual produces health by choosing a healthy diet measured by the Healthy Eating Index score (HEI), we have

$$HEI = g(E, \boldsymbol{p_f}, \boldsymbol{C}, \boldsymbol{v}), \tag{3}$$

where E is food expenditure and $\boldsymbol{p_f}$ is a vector of food retail prices. Given the two-day consumption data, we define equation (3) as

$$HEI_{it} = \boldsymbol{\alpha X_{it}} + \beta E_{it} + u_i + \varepsilon_{it}, \tag{4}$$

where HEI_{it} is the diet quality score of household member i at time t ($t = 1$ or 2 for two days of data) and $\boldsymbol{X_{it}}$ is the combination of $\boldsymbol{p_f}$, $\boldsymbol{C}$, and the observable health endowments contained in $\boldsymbol{v}$ of household member i at time t. E_{it} is the total expenditure of the foods consumed by the individual household member i at time t, and $\boldsymbol{\alpha}$ and β are conformable parameters to be estimated. The error term ε_{it} is used to account for data measurement and other errors.

In this model, u_i is used to capture the unobserved part in $\boldsymbol{C}$ (such as taste) and the unobserved parts of health endowment $\boldsymbol{v}$. This unobserved, individual-specific effect can be modeled as a fixed effects or random effects. The fixed effects can be estimated as a constant for each individual if the number of individuals is small, such as an intercountry comparison study (Greene, 2000). However, if the number of individuals is large (as in our data), then a random-effects model has to be used in order to avoid losing too many degrees of freedom.[2] For the random-effects model, the effects are randomly distributed among individuals and constant over time for each individual.[3]

In equation (4), both $\boldsymbol{X_{it}}$ and E_{it} include $\boldsymbol{p_f}$, the food price paid by individual i. We do not observe the actual prices paid by each individual in the data used in this study. However, we can estimate the prices using national average prices and simultaneously accounting for the quality variation suggested by Cox (1986). The total food expenditure in equation (4) is then calculated using the quantity and type of food consumed by the individual ($\boldsymbol{q}$) and the estimated prices. Since $\boldsymbol{q}$ is the choice of the individual, the calculated total food expenditure is endogenous, and the error terms between HEI_{it} and total food expenditure E are correlated. We thus define the total food expenditure as

$$E_{it} = \boldsymbol{\gamma Z_{it}} + e_{it}, \tag{5}$$

where $\boldsymbol{Z_{it}}$, like $\boldsymbol{X_{it}}$, is a vector of the individual characteristic variables that influence food quantity consumed and thus influence total food expenditure. That is, the variables used in estimating HEI_{it} in equation (4) could be the same as those used to estimate food expenditure in equation (5).

To estimate the model, we assume ε_{it} and e_{it} in equations (4) and (5) are jointly distributed normal with mean zero and variance-covariance matrix as

$$\boldsymbol{\Sigma} = \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon e} \\ \sigma_{\varepsilon e} & \sigma_e^2 \end{bmatrix}. \tag{6}$$

We further assume the random effect u_i in equation (5) is also distributed normally with mean zero and variance σ_u^2. Since the unobserved individual effects are not included, it is reasonable to

[2] Mancino, Todd, and Lin (2009) adopted a fixed-effect model using a similar dataset. They estimated a difference model to avoid the estimation of the large number of fixed-effect terms, which are invariant over time. However, the difference model also eliminates the effects of all the demographic variables that are constant over time.

[3] One problem in the random-effect model is the assumption of no correlation between the explanatory variables and the random-effect term. Bias estimates may be obtained if the correlation exists. As is discussed in the results section, we performed a Hausman test to test the assumption. Our test showed that the no correlation assumption cannot be rejected at the 5% level.

assume that u_i is not correlated with either ε_{it} or e_{it} (Greene, 2000). The reduced form of equation (4) can be expressed by replacing food expenditure using equation (5):

$$HEI_{it} = \boldsymbol{\alpha X_{it}} + \beta(\boldsymbol{\gamma Z_{it}}) + \omega_{it}, \tag{7}$$

where $\omega_{it} = \beta e_{it} + u_i + \varepsilon_{it}$. If both ε_{it} and e_{it} are temporally independent in the two time periods, the variance-covariance matrix of ω_{it} and e_{it} for the two time periods can be written as:

(8)

$$\boldsymbol{\Omega} = \begin{bmatrix} \sigma_\varepsilon^2 + \sigma_u^2 + \beta^2\sigma_e^2 + 2\beta\sigma_{\varepsilon e} & \sigma_u^2 & \beta\sigma_e^2 + \sigma_{\varepsilon e} & 0 \\ \sigma_u^2 & \sigma_\varepsilon^2 + \sigma_u^2 + \beta^2\sigma_e^2 + 2\beta\sigma_{\varepsilon e} & 0 & \beta\sigma_e^2 + \sigma_{\varepsilon e} \\ \beta\sigma_e^2 + \sigma_{\varepsilon e} & 0 & \sigma_e^2 & 0 \\ 0 & \beta\sigma_e^2 + \sigma_{\varepsilon e} & 0 & \sigma_e^2 \end{bmatrix}.$$

Putting equations (5) and (7) together, we consider two time periods. We thus have four equations that are jointly normal distributed. The log-likelihood function to estimate equations (5) and (7) simultaneously is therefore

$$LL_i = -T\ln(2\pi) - \frac{1}{2}\ln|\boldsymbol{\Omega}| - \frac{1}{2}(\boldsymbol{\omega_i' e_i'})\boldsymbol{\Omega}^{-1}\begin{pmatrix}\boldsymbol{\omega_i} \\ \boldsymbol{e_i}\end{pmatrix}, \tag{9}$$

where

$$\boldsymbol{\omega_i} = \begin{pmatrix} HEI_{i1} - \boldsymbol{\alpha X_{i1}} - \beta(\boldsymbol{\gamma Z_{i1}}) \\ HEI_{i2} - \boldsymbol{\alpha X_{i2}} - \beta(\boldsymbol{\gamma Z_{i2}}) \end{pmatrix}, \; \boldsymbol{e_i} = \begin{pmatrix} E_{i1} - \boldsymbol{\gamma Z_{i1}} \\ E_{i2} - \boldsymbol{\gamma Z_{i2}} \end{pmatrix} \tag{10}$$

and $T = 2$. Model estimates can be obtained from maximizing the sum of equation (9) over all individuals.

Given model estimates, it is possible to obtain variable elasticities, which capture the effects of food costs and other variables used in policy analysis. The derivation of elasticities is provided in the appendix.

Data

Data from the National Health and Nutrition Examination Survey (NHANES) 2003–04 were used for this study. NHANES collects information about participants' food consumption, demographic and socioeconomic characteristics, and health information obtained during a four-hour medical examination in a mobile examination center. As part of this exam, an in-person interviewer collects a twenty-four-hour dietary recall; a second day of dietary recall is collected by telephone within ten days of the first. Information about dietary intake for adults is self-reported. Most individuals eat different foods on the two days, and some change their food purchase habits (for example, going out to eat one day and eating only food purchased at a grocery store on another day). These differences between the two days will allow us to examine the impact of food costs and individual economic and social demographic variables on diet quality by controlling for the unobserved individual specific effect (for example, taste), which usually does not change over a short period of time.

The interviewer codes the dietary recall as either reliable and meets minimum criteria or not reliable and does not meet the minimum criteria. If the interviewer codes the interview as not reliable, she or he makes a notation in the log indicating the reasons why the interview is not reliable (National Health and Nutrition Examination Survey, 2002). Only data coded as reliable and meeting the minimum criteria are included in the publically released dataset. The data also include pseudo-primary sampling units (PSU) and pseudo-stratum that can be used to control for the complex sample design in certain models. We use them in our model to account for regional variation. While these are not perfect measures of geographic location, sample designers do take the region into account when assigning the pseudo-PSU and pseudo-strata. More information on the NHANES can be found elsewhere (Centers for Disease Control and Prevention, 2003–04). We included adults ages twenty and over with a reliable dietary recall for both of the two days. Once observations with missing information were removed, the final sample size is 3,802 individuals.

The dietary data are reported in a multipass interview. The interviewer reviews an initial list of foods generated by the participant and reminds him or her of commonly forgotten foods such as candy on a coworker's desk and foods and beverages consumed as secondary activities, including sitting at a desk, driving, or watching TV. Despite this multipass process, an underreporting bias has recently been documented by Archer, Hand, and Blair (2013). That is, participants neglect to report certain foods, particularly fats and sweets. Underreporting also appears to be more common among overweight and obese individuals. A recent editorial in the *Journal of the American Medical Association* acknowledges the underreporting and widespread awareness of underreporting, but cites the difficulty—if not impossibility—of collecting perfect dietary data (Mitka, 2013). Even given the awareness of underreporting, these data continue to be used in major government programs such as the *Dietary Guidelines for Americans* (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010) and in setting the maximum allotment for the Supplemental Nutrition Assistance Program (SNAP) (Carlson et al., 2007). As will be discussed in more detail, we estimate both the diet quality and the total daily expenditure on the foods that are actually reported. The underreported foods would most likely increase total daily expenditure (more food items) and decrease diet quality, since they tend to be high in added sugars and fat. Thus, the underreporting bias that may exist in the data means that we have likely underestimated the cost of the less healthy diets, making any findings from this study regarding cost and diet quality more robust.

Diet Quality Measure

We use the Healthy Eating Index-2005 (HEI-2005), developed by the USDA (Guenther et al., 2006) to measure diet quality from what respondents reported consuming. This one-hundred-point scale measures diet quality in terms of compliance with the key, diet-related recommendations of the *Dietary Guidelines for Americans 2005* (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2005). The index has been used by others to measure a healthy diet (for example, Beydoun and Wang, 2008; Mancino, Todd, and Lin, 2009; Savoca et al., 2009; Volpe and Okrent, 2012; Volpe, Okrent, and Leibtag, 2013; Variyam et al., 1998).

The HEI-2005 is calculated by comparing individual reported consumption with the recommended consumption provided in the *Dietary Guidelines for Americans 2005* (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2005). Total food consumed by each individual is gauged by twelve components, with a possible maximum total score of 100 points. The MyPyramid Equivalent Database (Bowman, Friday, and Moshfegh, 2008) is used to calculate the quantity consumed from each food group and subgroup (total fruit, whole fruit, total vegetables, dark green and orange vegetables and legumes, total grains, whole grains, milk, meat and beans, and oils). For most components, higher intakes result in higher scores. However, for three components (saturated fat; sodium; and calories from solid fat, alcoholic beverages, and added sugars (SoFAAS)), lower intake levels result in higher scores because lower intakes are more desirable. A higher score represents a healthier diet. The mean HEI-2005 score for adults age twenty and over is 51 points for day 1 and 53 points for day 2, with a standard deviation of only 0.55 to 0.57, indicating that there is plenty of room for diet improvement (table 1). Although scores are bounded by 0 and 100, the data are not censored, because there are no scores with a value of 0 or 100.

Table 1. Summary Statistics

Variable	Definition	Day 1 Mean	Day 1 Std Err	Day 2 Mean	Day 2 Std Err
HEI-2005	Healthy Eating Index	51.25	0.55	53.17	0.57
Cost					
Total daily cost ($)	Cost for 1 day ($)	5.55	0.10	5.42	0.08
Food Behaviors					
% store	% of energy purchased from store (omitted)	0.71	0.01	0.75	0.01
% other source	% of energy from other sources such as school cafeteria, soup kitchen etc. (omitted)	0.02	0.00	0.02	0.00
% fast food	% of energy purchased at counter-service restaurants	0.14	0.01	0.12	0.01
% table rest	% of energy purchased at table-service restaurants	0.10	0.00	0.09	0.01
% other rest	% of energy purchased at other restaurants	0.02	0.00	0.02	0.00
% breakfast	% of energy consumed at breakfast	0.17	0.01	0.20	0.00
% lunch	% of energy consumed at mid-day meal	0.25	0.01	0.26	0.00
% dinner	% of energy consumed at evening meal (omitted)	0.37	0.00	0.37	0.00
% snack	% of energy consumed as snacks	0.21	0.01	0.18	0.00
Mon-Thur	Dietary recall on Monday-Thursday	0.57	0.02	0.62	0.02
Friday	Dietary recall on Friday	0.15	0.01	0.10	0.01
weekend	dietary recall on Saturday-Sunday (omitted)	0.28	0.01	0.28	0.01
Health Behaviors					
Supplement	Take at least 1 supplement in past month	0.56	0.01		
Sedentary	Exercise less than 30 minutes most days (omitted)	0.42	0.02		
Active	Exercise 30-60 minutes most days	0.19	0.01		
Very active	Exercise more than 60 minutes most days	0.39	0.02		
Not smoking	Not currently smoking	0.75	0.01		
Smoker	Currently smoking (omitted)	0.25	0.01		
Metabolic count	Count of number of metabolic syndrome symptoms that doctor has told individual: hypertension, diabetes, elevated cholesterol, and overweight	1.01	0.03		
Demographic Variables					
Female	Female	0.52	0.01		
Male	Male (omitted)	0.48	0.01		
Income ($)	Household income	45,744.00	1,406.72		
College	College education	0.24	0.02		
Less than college	Has not received a 4 year college degree (omitted)	0.76	0.02		
Age	Age in years	46.83	0.56		
Household size	Household size	2.89	0.05		
English	Speak English at home (omitted)	0.93	0.02		
Spanish speaker	Speak Spanish at home	0.05	0.01		
Other language	Speak another language at home	0.02	0.01		
Native	Native-born (omitted)	0.88	0.02		
Immigrant	Immigrant	0.12	0.02		
White	Non-Hispanic White (omitted)	0.74	0.04		
Hispanic	Hispanic Origin	0.10	0.02		
Non-Hispanic, black	Non-Hispanic, Black	0.11	0.02		
Other race	Mixed or Other race or ethnicity	0.05	0.01		
Single	Not married or living as married, including divorced	0.36	0.02		
Partnered	Married or living as married (omitted)	0.64	0.02		

Notes: Proportions for some variables may not add to 1 due to rounding.
Source: NHANES 2003–04 and CNPP Food Prices Database, 2004.

Total Daily Cost

To estimate daily total cost, a price per edible gram was obtained for each food product and nonalcoholic beverage reported to be consumed by NHANES participants in a day.[4] The daily total cost is then the sum of all the individual food costs. Since the NHANES does not collect information on food prices or expenditures for foods consumed, we use the 2003–04 CNPP Food Prices Database (Carlson et al., 2008; Center for Nutrition Policy and Promotion, 2009) to calculate the prices of foods in the consumed form. The database estimates are national average prices for food at home—which account for the food purchased but lost either in preparation (peels, seeds, shells, bones and skins) or through cooking (moisture loss)—and give the cost of the food in its consumed form. For foods purchased at sources other than stores, we adjusted the cost upward using an adjustment of between 1.4 and 2.0, depending on the type of establishment (e.g., fast food, deli, table service, recreation facility, and nonschool cafeteria). We believe this is a conservative estimate of the cost of food away from home over food at home because restaurant meals can be considerably more than twice as expensive as the price of the same meal prepared at home. In order to test the impact of our food-away-from-home adjustment, we also estimated the model using an adjustment of 3.4 to 4.0.

Our mean total daily food cost is $5.55 for day 1 and $5.42 for day 2, with relatively small standard errors of ten and eight cents (see table 1), while the mean total daily cost estimate with the higher food away from home adjustment factor is $7.37. Our daily cost estimates shown in table 1 (conservative adjustment for food away from home) are about 15% lower than the 2004 Consumer Expenditure Survey per person total food expenditure estimates (U.S. Department of Labor, 2004) of $6.34/day, while the mean with the higher adjustment is higher than the measured mean. This suggests that estimating the model with both adjustment levels will reveal whether the conservative adjustment factor distorted the relationship between diet quality and diet cost.

Figure 1 shows the correlation of HEI-2005 scores and daily costs by quartiles of HEI. For those with very low HEI-2005 scores (panel 1), there is a slight correlation between diet quality and expenditure, but this relationship appears to disappear at higher levels of HEI-2005 (panels 2, 3, 4). The mean expenditure for both very healthy (high HEI-2005 scores, panel 4) and less healthy diets (low HEI-2005 scores, panel 1) is less than the sample mean total daily cost of food ($5.48). It would appear from this plot that significant improvements in diet quality can be made by some individuals by spending at current levels and making different food choices. If the consumers with low HEI scores (panel 1) have full information on food prices and healthy food options and thus make the choice to consume a less healthy diet within their budget constraint, then the shift to a healthier diet would represent a choice resulting in a lower utility. However, if consumers do not have full information on the options at their budget constraint and a healthier diet is desirable, then this chart demonstrates that improvements in diet quality (and utility) are possible. Whether or not consumers are working at full information is beyond the scope of this paper.

Table 1 reports the mean and standard error of variables used in this analysis using the sample weights and controlling for the complex sample design. The variables that describe the food choices study participants make are listed under food behaviors. About 71% of calories consumed are from food purchased in stores, with the rest coming from away-from-home sources such as restaurants, fast food restaurants, and cafeterias. Only 867 individauls out of 3,802 in our sample purchased all of their food from stores on both days. This affirms the important role of food away from home in the American diet, which cannot be ignored.

Turning to health behaviors, over half of the sample takes a dietary supplement and does not currently smoke. The value of health might be interpreted as a discount rate (Huston and Finke, 2003). Those with a high discount rate have a low value for future health because they are not willing to invest time and other resources now for future improvements. We expect that these individuals would also consume less healthy diets. For example, individuals who smoke are assumed to have

[4] Since we did not have prices for alcoholic beverages, we re-estimated the HEI scores without alcoholic beverages.

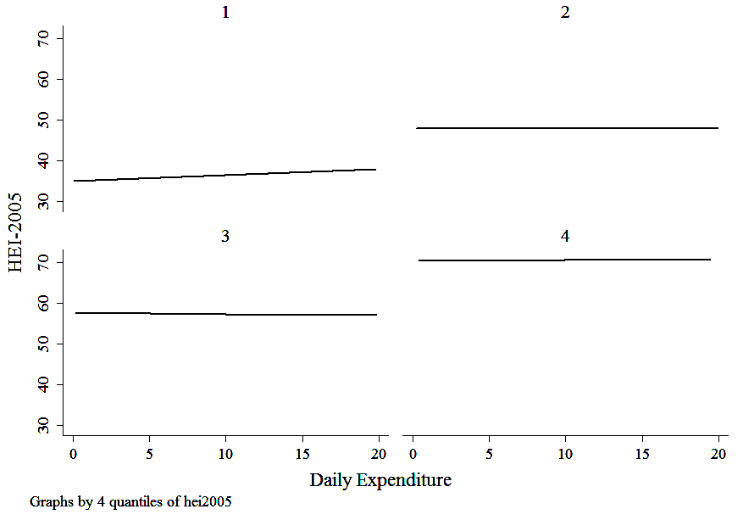

Figure 1. Correlation of HEI and Total Daily Cost by HEI-2005 Quartiles

Source: Estimated from NHANES 2003–04 and CNPP Food Prices Database.

a high discount rate for future health because they are not willing to forgo the immediate pleasure of smoking or invest the time in attending a smoking cessation program to reduce the risk of lung cancer in the future. Other research has shown that smokers also consume less healthy diets (Ma, Betts, and Hampl, 2000). Those who exercise are assumed to have a low discount rate for future health because they are willing to invest the time to exercise in order to gain the benefit of improved health in the future.[5] The number of metabolic syndrome conditions indicates the risk level of cardiovascular disease (Grundy et al., 2004) and is measured by whether a health care provider has previously informed the participant that he or she has hypertension, diabetes, elevated cholesterol, or is overweight. While metabolic syndrome symptoms may indicate a previously high discount rate for health, the fact that a health care provider has discussed them with the participant may indicate a lower discount rate, as the individual makes attempts to moderate the impact of the symptom by eating a healthier diet.

Results

We maximized the sum of equation (9) using GAUSS (Aptech, 2010) to simultaneously obtain the coefficients of both the diet-quality and diet-cost equations (results not shown). From the estimated coefficients we calculated the continuous variables' elasticities, following the elasticity equations provided in the Appendix.

As discussed in the model section, the direct estimation of the random-effect model may be biased due to the correlation between the random-effect term and the explanatory variables. We test this with a Hausman-type test using the results of a first-difference model with the time variant variables. However, all other variables that are constant over time are eliminated from the model. The elasticity estimates for the time variant variables from the first-difference model are provided in table 2. The Hausman-type test is as follows: We have nine time-variant variables including food expenditure. We estimate the expenditure equation defined by equation (7) first, then use the predicted expenditure to estimate the HEI equation given by equation (6) to account for possible endogeneity bias raised by food expenditures. Suppose $\boldsymbol{b}$ is the OLS estimate of equation (6) using

[5] Individuals who exercise also gain more immediate benefits such as increased energy and better weight management.

Table 2. HEI Elasticities of the First-Difference Model

	Elasticity	Std Err
Cost		
Total daily cost ($)	0.0596*	0.0089
Food Behaviors		
% fast food	−0.0227*	0.0023
% table rest	−0.0162*	0.0018
% other rest	−0.0013	0.0010
% breakfast	0.0018	0.0060
% lunch	0.0178*	0.0057
% snack	−0.0076	0.0049
Mon-Thur	0.0235*	0.0037
Friday	0.0016	0.0017

Notes: Single asterisks (*) indicate significance at or above the 5% level.

the difference model (table 2) and $\boldsymbol{br}$ is the ML estimate of equation (6) using the random-effect model (table 3), then $(\boldsymbol{b}-\boldsymbol{br})'\boldsymbol{V}(\boldsymbol{b}-\boldsymbol{br})^{-1}(\boldsymbol{b}-\boldsymbol{br}) \sim \chi^2(k)$, where k is the number of elements in $\boldsymbol{b}$, and $\boldsymbol{V}(\boldsymbol{b}-\boldsymbol{br})$ is the variance-covariance matrix of $(\boldsymbol{b}-\boldsymbol{br})$. The test statistic for our model is 16.31, which is smaller than the critical value 16.92 with $k=9$. That is, we cannot reject the assumption of no correlation between the explanatory variables and the random-effect term at the 5% level. Therefore, we focus the discussion only on the results from the direct estimation of the random-effect model.

Table 3 shows the elasticity results for the diet-quality equation, while table 4 shows the cost elasticity.[6] These estimates are for the sample and do not necessarily represent the U.S. population. For the binary indicator variables, we calculated the marginal impact as the variable changes from a value of 0 to 1. In order to measure the goodness-of fit of our model, we calculated the R-squared values using the squared correlation between the actual value and the predicted value of the dependent variables. The R-squared values for the diet-cost and diet-quality equations are 0.30 and 0.28, respectively. This is one of the highest R-squared values we have seen for predicting diet quality, even with a high number of variables (Carlson and Gerrior, 2006; Huston and Finke, 2003; Mancino, Todd, and Lin, 2009; Todd, Mancino, and Lin, 2010; Variyam, Blaylock, and Smallwood, 1996). However, these results also show that significantly more research is required to understand the factors that contribute to a healthy diet.

Our major finding is that there is no single factor that policy makers can use to improve the diet quality of Americans. Factors such as health behaviors and indicators as well as demographic variables appear to have a stronger association with better food choices than does expenditure. Other researchers actually find decreased costs as families shift from an unhealthy diet to a healthier one (Mitchell et al., 2000; Raynor et al., 2002). Schroeter, Anders, and Carlson (2013) find that total daily diet cost over two days is not significantly associated with diet quality in their model of risky behaviors including TV watching, computer games, smoking and alcohol consumption, BMI, elevated blood cholesterol levels, diabetes, and low mental and physical health.

While diet cost is statistically significantly associated with diet quality, the elasticity (0.065, table 3) suggests a fairly small improvement in diet quality for a fairly substantial change in diet cost. Raising food expenditures $1 (just under 20% of the average daily expenditure) will increase HEI-2005 scores by only 1.9 points, to about 54 points, leaving diet-quality scores well under

[6] Tables 3 and 4 do not include the twenty-eight binary variables created from the NHANES PSU and stratum, which were included to control for regional variation. In both the diet-quality equation and expenditure equation, seventeen were significant at the p=0.05 level.

Table 3. HEI Elasticities and Marginal Effects

	Marginal[a] or Elasticity	Std Err
Cost		
Total daily cost ($)	0.0650***	0.0057
Food Behaviors		
% fast food	−0.0261***	0.0018
% table rest	−0.0155***	0.0012
% other rest	−0.0003	0.0007
% breakfast	0.0106**	0.0040
% lunch	0.0195***	0.0041
% snack	−0.0070*	0.0033
Monday–Thursday[a]	0.0356***	0.0062
Friday[a]	0.0121	0.0087
Health Behaviors		
Supplement[a]	0.0425***	0.0074
Active[a]	0.0246*	0.0097
Very active[a]	0.0376***	0.0077
Not smoking[a]	0.1034***	0.0084
Metabolic count	0.0100**	0.0036
Demographic Variables		
Female[a]	0.0431***	0.0070
Income ($)	0.0120**	0.0043
College[a]	0.0674***	0.0092
Age	0.0663***	0.0103
Household size	−0.0278***	0.0078
Immigrant[a]	0.0690***	0.0115
Spanish speaker[a]	0.0714***	0.0172
Other language[a]	0.0384	0.0285
Hispanic[a]	0.0044	0.0134
Non-Hispanic, Black[a]	−0.0249*	0.0102
Other[a]	0.0366	0.0196
Single[a]	−0.0117	0.0078

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 5%, 1%, and .1% levels. Not shown are the twenty-eight binary variables created from the NHANES PSU and stratum. Seventeen were significant at or above the 5% level.
[a] Indicates the result shown is a marginal change from 0 to 1 with other variables held at the mean.
Source: Estimated from NHANES 2003–04 and CNPP Food Prices Database

desirable levels.[7] Using the higher adjustment factors for food away from home, we estimate the elasticity drops to 0.0478, implying a $1 increase in food expenditures will increase HEI-2005 scores by 1.6 points (data not shown). Of all the factors we considered, the decision not to smoke has the largest association with the HEI-2005 scores (5.4 points). This confirms earlier research by Ma, Betts, and Hampl (2000), who also find that smokers have worse diets than nonsmokers. The largest statistically significant impact on total daily diet cost is gender (table 4)– females spend about 20% less—about $1—on food than males; this is not surprising since females typically have lower energy requirements and thus tend to eat less than males when consuming the same foods.

[7] For a 2,000 calorie diet, a 1.9 point increase is equivalent to just over one more ounce-equivalents of whole grains, one third a cup-equivalent of dark green and orange vegetables and legumes, or just under a cup-equivalent of milk. Each of these can be purchased for less than $1 (Carlson and Frazão, 2012).

Table 4. Cost Elasticities and Marginal Effects

	Marginal[a] or Elasticity	Std Err
Food Behaviors		
% fast food	0.0705***	0.0030
% table rest	0.0664***	0.0023
% other rest	0.0127***	0.0010
% breakfast	−0.0376***	0.0067
% lunch	0.0115	0.0065
% snack	0.0297***	0.0055
Mon–Thur[a]	−0.0400**	0.0138
Friday[a]	−0.0127	0.0172
Health Behaviors		
Supplement[a]	0.0806***	0.0107
Active[a]	0.0730***	0.0148
Very active[a]	0.0732***	0.0113
Not smoking[a]	0.0005	0.0119
Metabolic count	0.0146**	0.0054
Demographic Variables		
Female1	−0.2019***	0.0102
Income ($)	0.0583***	0.0061
College[a]	0.0877***	0.0151
Age	−0.2332***	0.0149
Household size	−0.0098	0.0107
Immigrant[a]	0.0738***	0.0138
Spanish speaker[a]	−0.0560*	0.0222
Other language[a]	−0.0845*	0.0395
Hispanic[a]	−0.0469**	0.0181
Non-Hispanic Black[a]	−0.1163***	0.0138
Other race[a]	0.0011	0.0317
Single[a]	−0.0244*	0.0112

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 5%, 1%, and .1% levels. Not shown are the twenty-eight binary variables created from the NHANES PSU and stratum. Seventeen were significant at or above the 5% level.
[a] Indicates the result shown is a marginal change from 0 to 1 with other variables held at the mean.
Source: Estimated from NHANES 2003–04 and CNPP Food Prices Database.

In order to better interpret the results, we use the elasticity results from tables 3 and 4 to estimate the cost and diet quality changes for selected changes individuals could make to their food behaviors (figure 2) and the association between demographics and health behaviors and indicators with diet cost and diet quality (figure 3). For example, point B in figure 2 represents a consumer changing from purchasing a meal at a fast food or pizza delivery to purchasing a meal at a store, which we estimate as one-third of the calories consumed in the day. With other factors held at the mean, this change would reduce the daily diet cost by $0.92 and increase the HEI score by 3.25 points—more than the increase the same consumer would achieve by spending $1 more on food (point A, figure 2) but keeping other food behaviors the same. The only change that would increase the daily expenditure on food is to simply increase what is spent (point A).

Food Behaviors

In *Mindless Eating*, Brian Wansink (2006) notes that the average individual makes over 200 decisions a day about food. One set of decisions involves where the food should be purchased—from a store, a restaurant with table service, or other type of restaurant. In addition to the cost savings and diet improvement from switching from a fast food source to food at home (figure 2,

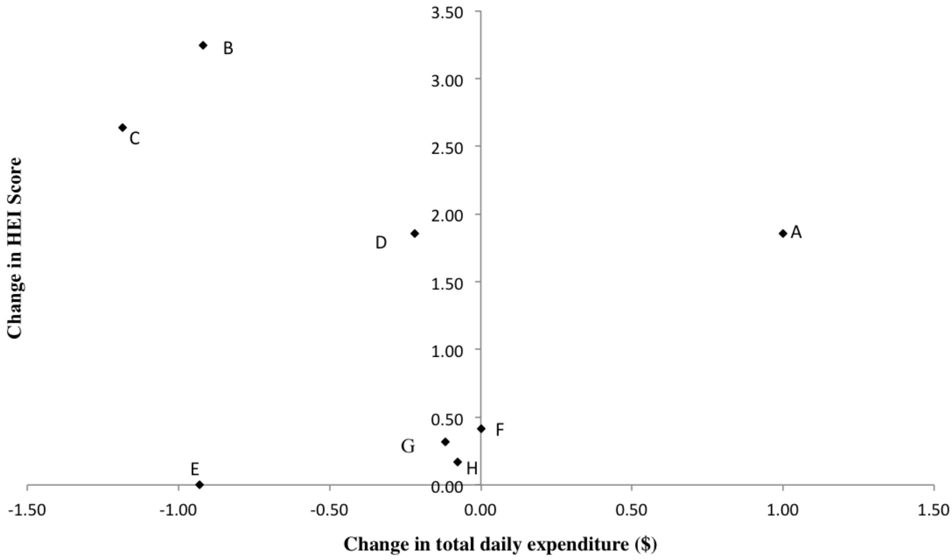

Figure 2. Estimated Impact of Food Behaviors on HEI and Expenditure

Key:
A Spend $1 more per day
B Replace one meal (-33% of calories) of fast food with store food
C Replace one meal (-33% of calories) of table service restaurants with store food
D Eat same on weekend as Monday and Thursday
E Replace one meal (-33% of calories) of other restaurants with store food
F Increase lunch calories by 10%
G Increase breakfast calories by 10%
H Decrease snack calories by 10%
Source: Estimated from marginal or elasticities in tables 3 and 4. Changes are estimated at the mean HEI score or food expenditure.

point B), switching from a table service restaurant will also save money ($1.19) and improve the HEI-2005 score by 2.64 points (figure 2, point C). Switching one meal from "other restaurants"[8] to food at home will also save money but have no impact on the HEI score (point E). We believe these cost savings are conservative and are purely a function of how much we inflated the cost of food-away-from-home foods over at-home prices. If we use the higher food-away-from-home adjustment factors, the elasticity in the diet-quality equation (table 2) is very close (-0.013 for the higher factors versus -0.0155), but the cost elasticity increases to 0.1425 from 0.0664, indicating a higher cost savings (results not shown).

Our results are in the same direction as other research for both cost and improvements to diet quality. In their examination of cross tabulations of data from the Consumer Expenditure Survey, Stewart and Blisard (2008) also find that groups that consume more food away from home, such as households headed by individuals aged 55–64, have higher total food expenditures. Using the same data as our study, Mancino, Todd, and Lin (2009) also find that away-from-home food sources lower HEI-2005 scores.

Other authors examine the impacts of day of the week and consuming breakfast and snacks on energy and micronutrient intake (International Food Information Council Foundation, 2008; Kant et al., 2008; Kerver et al., 2006; Morgan, Zabik, and Stampley, 1986; Haines et al., 2003). We find that consuming a greater percentage of energy at breakfast (point G, figure 2) and lunch (point F) as opposed to dinner is associated with a higher HEI score. Every 10% increase in total calories consumed at breakfast or lunch is associated with a 0.32 or 0.41 point increase in HEI score. In the

[8] Other restaurants include cafeterias, bars and taverns, entertainment venues, and other food-away-from-home sources.

case of breakfast, this also saves an estimated $0.12 per day. Further examination of the data finds that breakfast eaters consume more fruits, vegetables, grains, and milk and less saturated fat and extra calories such as solid fat and added sugars. Fruits, vegetables, grains, and milk have been shown to cost less per average amount consumed than foods that are high in fats and added sugars (Carlson and Frazão, 2012). Other research finds that breakfast skippers do not make up the nutrients and food group recommendations they did not consume at breakfast (for an overview see International Food Information Council Foundation, 2008; Kerver et al., 2006).

On the other hand, consuming a lower percentage of calories as snacks (point H) as opposed to dinner is associated with a slightly higher HEI score. We estimate that decreasing the percent of total calories from snacks by ten percentage points will decrease the daily cost by $0.08 and increase the HEI-2005 score by 0.17 points. This is also found in other research that directly compares the price of snack foods high in fat or added sugars to fruits and vegetables (Frazão et al., 2012). Switching to fruits and vegetables for snacks would lower the percent of calories consumed as snacks. Foods consumed Monday through Thursday are healthier and less expensive than foods consumed on the weekend (point D). One's HEI score is 1.86 points higher and $0.22 less is spent on food on Monday through Thursday than on the weekend. This confirms earlier research, which found that adults consume more food energy, more total fat, and a higher percent of calories on Friday through Sunday than on Monday through Thursday (Haines et al., 2003).

The findings from the food behavior variables (figure 2) suggest that Americans wishing to eat a healthier diet could focus on habits such as purchasing food from stores instead of restaurants, spreading calorie consumption out during the day, choosing lower calorie snacks, and making healthier choices on the weekends. We estimate that these changes may lower the daily food costs as well.

Health Behaviors and Indicators, and Demographics

We turn now to examining the relationship between health behaviors and indicators and demographic variables versus diet quality and diet cost (figure 3). The horizontal line in figure 3 represents the change in HEI score when consumers spend $1 more on food. Many demographic and health behavior indicators suggest that individuals make food choices that increase diet quality and cost less than $1/day (points A–G). Individuals who may be perceived to eat healthier diets, such as those who exercise (H) or take vitamin supplements (E), do spend more on food; this may contribute to the perception that healthy diets cost more. However, nonsmokers (A) compared to smokers have the highest HEI score difference, and their estimated daily total cost is the same. Unlike the changes listed in figure 2, these factors are not things the consumer could or would change for the sole purpose of improving their diet. Instead, some of them should be interpreted as signals of the individual's value of health, their food environment, or ability and desire to follow advice from health care professionals.

We find that people who exercise have healthier diets (HEI scores 2–4% greater) than those who are sedentary (points F and H, figure 3). It is not possible to determine from our data whether this is because those who exercise value health in general and thus seek out healthy foods; they are exposed to more nutrition information, such as through their gym or the media; or another reason. Each additional metabolic syndrome condition is associated with a higher HEI score (point J). It appears that people who have been told by a doctor that they have a condition that puts them at a higher risk of cardiovascular disease are trying to improve their health by eating a better diet. This finding was previously noted in an earlier intervention study that found that women who either had a health condition or had a close friend or relative with a health condition were more motivated to make healthy improvements to their diet (Bhargava and Hays, 2004). Individuals who take a supplement at least once a month scored 2.22 points higher on the HEI score than those who do not take supplements (point E). Schroeter, Anders, and Carlson (2013) also find that people who take supplements consume healthier diets.

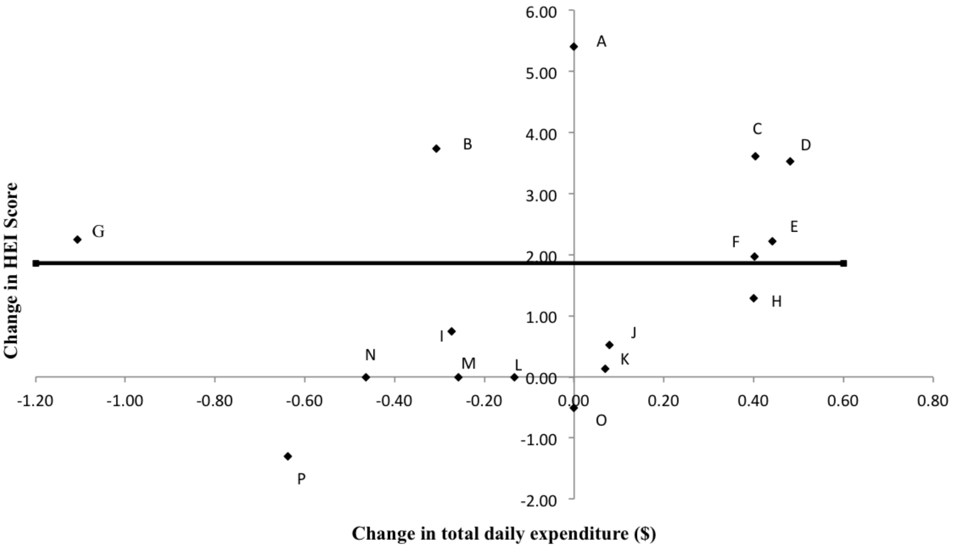

Figure 3. Estimated Impact of Health and Demographic Indicators on HEI and Expenditure

Notes: The horizontal line indicates the predicted change in HEI achieved by spending $1 more per day (point A in figure 2).
Key:
A Nonsmokers
B Persons who speak primarily Spanish
C Persons who are immigrants
D Persons with a college degree
E Supplement users
F Persons who exercise at least sixty minutes on most days
G Females
H Persons who exercise thirty to sixty minutes most days
I Age increases by ten years
J Add one more metabolic syndrome symptom
K Income increases by $10,000
L Persons who are not married or living as married
M Persons of Hispanic ethnic origin
N Persons who speak a language other than English
O Add 1 member to household
P Persons who are black or African-American, but not Hispanic
Source: Estimated from marginal or elasticities in tables 3 and 4. Changes are estimated at the mean HEI score or food expenditure.

We also find that individuals who take supplements, exercise, or have more symptoms related to a metabolic syndrome also have higher daily diet costs (points E, F, H, and J). This finding may contribute to the perception that healthy diets cost more. If these consumers are perceived as health conscious and consumers of healthy foods and they happen to select the more expensive healthy foods over the less expensive ones, then others may perceive that the foods these individuals select are somehow better than the less expensive options. Further research is needed to determine whether this is the case. The factor with the highest association with diet quality is smoking: nonsmokers have a higher diet quality (point A) than smokers, and this behavior is not associated with diet cost. Ma, Betts, and Hampl (2000) also find that smokers have poorer quality diets.

Demographic confounders are important control factors in predicting food choices. Other studies have found that (for a variety of reasons), these factors are related to diet quality (for example, Bhargava and Hays, 2004; Hiza et al., 2013; Savoca et al., 2009; Variyam et al., 1998; Huston and Finke, 2003; Kinsey, 1994; Aldrich and Variyam, 2000). Our results for gender (point G, figure 3), age (point I), education (point D), and race and ethnicity (points M and P) are similar to those of other researchers. Diet quality increases with age and education, females have a higher diet quality than males, and African-Americans have a lower diet quality than others. The associated shifts in HEI score are small, but larger than the associated increase when spending $1 more per day on food (horizontal line on figure 3). Our findings for the association between age, race and ethnicity, education, and income are also in line with other research (Blisard and Stewart, 2007; Stewart and Blisard, 2008). We find only a modest association with diet quality and income.

Increasing from the mean income of $45,744 to $55,744 (22%) would raise the HEI score by 0.14 points at the mean (point K). Income has an association with diet quality in other research (Bhargava and Hays, 2004; Kinsey, 1994; Savoca et al., 2009; Variyam et al., 1998). For total HEI-2005, Hiza et al. (2013) only finds a statistical difference between the lowest (less than 130% of the federal poverty line) and the highest income group (over 500%). While the difference found by Hiza et.al. (55 points versus 58 points) is statistically significant, the results indicate that all income groups consume diets that deviate considerably from dietary recommendations. Unlike other studies, we control for food cost in our model, and income is still significant, although the significance is very small. We differ with other estimates for our results on household size: We find that single individuals spend $0.13 less than adults with partners and that the household-size variable is not significant in the cost equation (point O). In contrast, Blisard and Stewart's (2007) cross-tabulations of data from the Consumer Expenditure Survey find that single-person households spend more than twice as much per capita than households with at least six members. The difference could be in part due to the fact that we control for more variables and that we use national average prices, which do not allow for the economies of scale larger households may gain by purchasing foods in larger quantities.

The important conclusion to draw from figures 2 and 3 is that the variables that are directly linked to food choices (figure 2)—where the food was purchased, how the food energy is spread out throughout the day, and the choices made during the week versus the weekend—all suggest that consumers can save money and improve their diet. In contrast, the variables that are considered indicators of healthy behavior (for example, exercise and not smoking) or demographic variables that are associated with better diet quality (such as age and gender) show mixed results in terms of their relationship with expenditure and diet quality.

Implications

Our analysis does not confirm the popularly held belief that healthy food is more expensive than less healthy food. Our results show that there are no easy answers to improving the diets of Americans but that cost is not a major barrier. Analysis of the data used in this study suggests that significant gains in the diet quality of American adults can be made without increases to the food budget, but consumers will need to make different food choices. Continued awareness of factors that are significant in predicting both diet quality and food expenditure may assist nutrition educators in developing and targeting their programs.

For individuals who have not made investments in long term health (such as quitting smoking or starting a regular exercise program) small steps with more immediate outcomes than long-term health are needed. Eating breakfast rather than skipping it and making use of the growing availability of nutrition information at restaurant and fast food outlets would also help, especially for individuals who frequently eat out. In addition, nutrition educators may want to develop programs that help people make healthier food choices on typical nonwork days. The daily choice of where to obtain food also makes a difference since those who consumed foods at fast food and table-service restaurants have lower diet quality (and higher costs) than those who purchase their food from stores and prepare it at home. Combined with other research, it would appear from these results that consumers can reduce total food costs and increase their diet quality by selecting lower calorie healthy choices for snacks (such as low-cost fruits and vegetables). Nutritionists have made both of these recommendations, but prior to our analysis the impact on the total food budget had not been examined. Finally, it may be necessary to develop policies or public health campaigns that promote and raise awareness of lower cost healthy foods in order to combat the popular belief that healthy food is more expensive.

The limitations of our study should be noted. First, while NHANES is typically considered to be representative of the U.S. population, we use a subset of NHANES, so results may not be representative of the entire U.S. population. Second, we used national average prices, so these are not the prices that individuals actually faced. We are able to control for overall regional variation in the cost and quality equations by using the sample's pseudo primary sampling units (PSU) and pseudo-strata. To the extent that relative price differences between different foods (e.g., potatoes versus potato chips) are the same across the country, regional variation should matter less than other factors. A recent analysis finds that relative price difference holds for some comparisons, but not all (Todd, Leibtag, and Penberthy, 2011). However, regional price differences appear to be less than differences within a food group (Carlson and Frazão, 2012; Todd, Leibtag, and Penberthy, 2011). Future research is needed to further explore the relationship between regional or even market-level prices and diet quality.

Another limitation is that we are unable to control for the time cost for foods prepared at home. If the correlation between preparation time, healthfulness, and cost were consistent, it would be easy to say how this would bias our results. However, this relationship is not consistent. For example, frozen and rinsed canned vegetables require minimal preparation time and are generally less expensive than fresh forms (Stewart et al., 2011a), and they are usually as healthy. A family-size frozen lasagna takes about an hour to heat, while lentils and rice take about thirty minutes to prepare and cook; here the food with the longer cooking time is likely more expensive and less healthy. Further research needs to be done on the relationship between convenience, price, and healthfulness.

The third limitation is the lack of prices for alcoholic beverages and the omission of foods that study participants consumed but did not report. Since including alcohol and foods that are typically under-reported (those high in fat and added sugars) would lower diet quality and increase our estimated cost, our conclusion that spending more on food is not associated with a higher quality diet does not change.

This study's main strength is the use of individual consumption data in a panel data model that demonstrates the relationship between food expenditure and the healthfulness of the diet as measured by the HEI-2005. The model controls for the endogenous relationship between diet cost and diet quality and accounts for the unobserved individual specific effect on diet quality by using two days of dietary recall data in a random-effects panel data structure. This model can be extended for future work, including examining the relationship between cost and the individual HEI components such as fruit, vegetables, grains, and dairy.

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Appendix A: Elasticity Derivation

Elasticities for individual i are evaluated based on the expected values of the two endogenous variables given by equations (4) and (5). The two expected values can be written as

(A1) $$E(E_i) = \boldsymbol{\gamma}\overline{\boldsymbol{Z}}_{\boldsymbol{i}};$$

(A2) $$E(HEI_i) = \boldsymbol{\alpha}\overline{\boldsymbol{X}}_{\boldsymbol{i}} + \beta(\gamma\overline{\boldsymbol{Z}}_{\boldsymbol{i}}).$$

In order to obtain the effect of expenditure on individual i's diet quality, we derive the expected value of HEI on a given food expenditure as

(A3) $$E(HEI_i|E_i) = \boldsymbol{\alpha}\overline{\boldsymbol{X}}_{\boldsymbol{i}} - \frac{\sigma_{\varepsilon e}}{\sigma_e^2}(\gamma\overline{\boldsymbol{Z}}_{\boldsymbol{i}}) + \left(\beta + \frac{\sigma_{\varepsilon e}}{\sigma_e^2}\right)\overline{E}_i,$$

where a variable with a bar over it indicates the mean value of the variable over the two time periods.

The expenditure elasticity with respect to $\boldsymbol{Z}$ from equation (A1) is

(A4) $$\frac{\partial E(E_i)}{\partial \boldsymbol{Z}}\frac{\overline{\boldsymbol{Z}}_{\boldsymbol{i}}}{\overline{E}_i} = \frac{\gamma\overline{\boldsymbol{Z}}_{\boldsymbol{i}}}{\overline{E}_{i_i}},$$

which gives the percentage change in food expenditure (food exp) given a 1% change in $\boldsymbol{Z}$.

The diet quality elasticity with respect to food cost from equation (A3) is

(A5) $$\frac{\partial E(HEI_i|E_i)}{\partial E}\frac{\overline{E}_i}{\overline{\overline{HEI}}_i} = \left(\beta + \frac{\sigma_{\varepsilon e}}{\sigma_e^2}\right)\frac{\overline{E}_i}{\overline{\overline{HEI}}_i},$$

which gives the percentage change in HEI given a 1% change in food expenditure

The diet quality elasticities with respect to $\boldsymbol{X}$ and $\boldsymbol{Z}$ from equation (A2) are

(A6) $$\frac{\partial E(HEI_i)}{\partial \boldsymbol{X}}\frac{\overline{\boldsymbol{X}}_{\boldsymbol{i}}}{HEI_i} = \frac{\alpha\overline{\boldsymbol{X}}_{\boldsymbol{i}}}{HEI_i} \text{ and } \frac{\partial E(HEI_i)}{\partial \boldsymbol{Z}}\frac{\overline{\boldsymbol{Z}}_{\boldsymbol{i}}}{HEI_i} = \beta\frac{\gamma\overline{\boldsymbol{Z}}_{\boldsymbol{i}}}{HEI_i},$$

which gives the percentage change HEI given a 1% change in $\boldsymbol{X}$ or $\boldsymbol{Z}$.

For a common variable $\boldsymbol{W}$ in both $\boldsymbol{X}$ and $\boldsymbol{Z}$, the diet quality elasticity can be derived from equation (A2) as

(A7) $$\frac{\partial E(HEI_i)}{\partial \boldsymbol{W}}\frac{\overline{\boldsymbol{W}}_{\boldsymbol{i}}}{\overline{\overline{HEI}}_i} = (\boldsymbol{\alpha} + \beta\gamma)\frac{\overline{\boldsymbol{W}}_i}{\overline{\overline{HEI}}_i},$$

which gives the percentage change in HEI given a 1% change in $\boldsymbol{W}$.

For binary variables, we estimate the marginal impact of changing from one condition to another, where the other variables are held at their respective means. For example, if $\boldsymbol{Z}$ or $\boldsymbol{W}$ is binary, equations (A4) and (A7) can be adjusted to calculate the percentage change in the marginal effect as

(A8) $$\frac{\boldsymbol{\Delta E(E_i)}}{E_{\boldsymbol{i}}} = \frac{\gamma}{\overline{\overline{E}}_i};$$

(A9) $$\frac{\boldsymbol{\Delta E(HEI_i)}}{HEI_i} = (\boldsymbol{\alpha} + \beta\gamma)\frac{1}{\overline{\overline{HEI}}_i},$$

which gives the percentage change in food expenditure E (equation A8) and health dietary score HEI (equation A9) when a binary variable changes from 0 to 1.