The Economics of Health and Vitamin Consumption

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Abstract *We estimate the impact of vitamin supplement intake, lifestyle, health indicators, food culture, and demographics on diet quality outcomes as measured by the Healthy Eating Index−2005 (HEI). Our data consists of U.S. adults who participated in the 2003−2004 National Health and Nutrition Examination Survey. Alternative instrumental variable estimators explicitly address issues of endogeneity and complex sample design. Our empirical analysis demonstrates that diet quality is strongly interrelated with food culture. We suggest that vitamin consumption serves as another marker for healthy eating. This finding emphasizes the need to employ economic modeling when developing public policy to reduce obesity.*

Introduction

Recent nutrition studies suggest that the intake of vitamin supplements might be unnecessary and even harmful (Klein et al. 2011; Mursu et al. 2011; Wang 2011). Although most dieticians agree about eating a well-balanced diet, many health care professionals continue to recommend multivitamins to supplement low fruit and vegetable intake. Indeed, U.S. consumers only consume 64% of the vegetable servings and half of the fruit servings recommended by the U.S. Department of Agriculture Food Patterns (U.S. Department of Agriculture and U.S. Department of Health and Human Services [USDA/HHS] 2010), which are presented on the ChooseMyPlate.gov website (U.S. Department of Agriculture 2011). Simultaneously, solid fats, alcohol, and added sugars (SoFAAS) are consumed in amounts 2- to 3-fold their recommended limits (see table 5-1 in USDA/HHS 2010). Declining produce consumption patterns are commonly attributed to changing socio-demographics, rising demands for convenience foods, growing away-from-home food expenditures, and declining food preparation skills (e.g. (Mancino et al. 2009; Stewart and Blisard 2008).

Overall, these changes have contributed to consumers' more favorable attitudes towards nutritional supplements as a perceived alternative healthy way to improve diet quality (Pole 2007). In fact, nutritional supplement use has risen steadily over the past 40 years (Gahche et al. 2011). The Council for Responsible Nutrition (2005) reports occasional use of nutritional supplements for 62% of U.S. adults, whereas 46% are reported to take supplements regularly (Dickinson and Shao 2006). Preventative health care through greater adherence to dietary guidelines is estimated to potentially save between $21 billion and $43 billion each year in direct medical costs and lost productivity resulting from secondary chronic health problems due to poor diets (Frazão 1999; Kim et al. 2001; DeVol and Bedroussian 2007; Drichoutis et al. 2005). However, the *2010 Dietary Guidelines for Americans* state "a fundamental premise that nutrients should come primarily from foods . . . given that dietary fiber and other naturally occurring substances that may have positive health effects," (USDA/HHS 2010, p. 49). The recommendations also state that specific supplements may be needed for at-risk population groups such as postpartum women, as well as older Americans (USDA/HHS 2010).

This conflict suggests a need to understand the role of dietary supplements in U.S. consumer's diet-health behavior, and whether supplements are currently replacing or supplementing a healthy diet. In this context, two policy-related scenarios seem particularly relevant. It is possible that the intake of vitamin supplements by consumers who already eat a healthy diet might be harmful. Thus, the first policy scenario discourages the intake of "extra" vitamin supplements for the general population. The second policy scenario addresses consumers who are not willing to improve their eating habits, and thus take supplements to *replace* a healthy diet. In this case, it might be harmful to discourage supplement use in the general population.

In either case, evidence suggests it is important to continue emphasizing a healthy diet and to encourage supplement intake only for key subpopulations such as pregnant and lactating women, and individuals over fifty. To our knowledge, there currently exists no study of vitamin supplement intake and diet quality in the United States that also includes food culture and lifestyle features.

The objective of this paper is to determine the relationship between vitamin supplement intake and diet quality outcomes as measured by the Healthy Eating Index–2005 (HEI–2005) (Guenther et al. 2008), controlling for other influencing factors such as lifestyle, health indicators, food culture, and demographics. We use data from the 2003–04 U.S. National Health and Nutrition Examination Survey (NHANES) to estimate the contribution of vitamin supplement intake to individuals' total HEI–2005 score, as well as the fruit and vegetable component scores. The latter two indices are of particular concern to health policy-makers and U.S. produce growers alike. Previous research (Basiotis et al. 2002; Guenther et al. 2008; Stewart et al. 2003) has repeatedly discussed the policy challenges surrounding the cycle of low socio-economic status, poor diets, and poor health among U.S. consumers. We consider vitamin supplement intake in sub-populations who are especially at risk due to existing health conditions or other lifestyle factors. The empirical analysis explicitly addresses two frequent empirical problems encountered in cross-sectional and health behavioral analyses – endogeneity and measurement error. To avoid problems related to using unsuitable instruments commonly encountered in studies of nutrition and food choice, we contribute to the literature by comparing the performance of two alternative instrumental variable (IV) methods, Generalized Methods of Moments (GMM), and Two-stage Least Squares (2SLS), in estimating the impact of vitamin supplement intake on diet quality. We apply an IV estimation strategy using secondary and tertiary instruments to control for endogeneity bias as proposed by Lewbel (2012).

Model

Previous literature suggests that diet quality is a function of expenditure on foods, lifestyle, and several socio-demographic and other factors such as age, education, and gender. Our approach builds on this literature, and further assumes that a consumer's health behavior towards diet quality includes the decision to consume dietary vitamin supplements as part of their diet production function. A general model specification for an individual's diet quality, HEI_i, can thus be written as:

$$HEI_i = a_0 + a_1 V_i + \beta X_i + e_i \quad (1)$$

where V_i is vitamin supplement intake, X_i is a vector of explanatory variables including lifestyle, health indicators, food culture and cost, as well as socio-economic and demographic variables, a_0, a_1 and β are parameters to estimate and e_i is the error term. We label this specification the "Full Model."

The 2010 Dietary Guidelines for Americans specifically state that selected population groups are disproportionately affected by diet-health related chronic and associated health problems. The guidelines recommend that specific supplements may be needed for such population groups, including smokers and older Americans (USDA/HHS 2010). To more directly capture the impact of vitamin intake in these population groups, we develop a second model specification based on equation (1), where Xi, the vector of explanatory variables, includes lifestyle, health, food culture and cost factors, as well as socio-economic and demographic indicators commonly associated with populations deemed at-risk of suffering disproportionately from diet-health related disease and related chronic health conditions. This specification is labeled the "At-Risk Model".

Determinants of Diet Quality

Previous studies on food and health behavior suggest that an individual's diet quality can be attributed to factors ranging from lifestyle (e.g. physical activity, smoking), health indicators (e.g. obesity or overweight, cholesterol), to food culture (e.g. race, location of food consumption, household size), and demographics (e.g. age, income) (Arnade and Gopinath 2006; Beydoun and Wang 2008; Bhargava 2004; Bhargava and Hays 2004; Carlson and Gerrior 2006; Lang and Jebb 2003; Mancino et al.

2009; Stewart and Blisard 2008). Using data from the 2003–2004 NHANES, we test the relationship between vitamin supplements and diet quality while controlling for these other influencing factors.

Diet Quality

For our dependent variable, we measure diet quality using the USDA Healthy Eating Index–2005 (Guenther 2006). This score is calculated from actual dietary intake data, which NHANES measures using two 24-hour multi-pass dietary recall interviews. The first interview is conducted in person, while the second takes place via telephone within ten days of the first. The interviewer records the amount of food actually consumed, rather than the amount of food that is purchased, which allows for a more precise measurement of food intake. In addition, survey interview questionnaires aim at collecting supplemental consumption, lifestyle and demographic characteristics (Centers for Disease Control and Prevention [CDC] 2010). This study uses data from 6,187 adults who are 20 years and older. Table 1 provides an overview of the variables constructed from NHANES and used in the analysis, as well as the sample mean and standard deviation. We used sample weights to calculate the means, and controlled for NHANES complex sample design when calculating the standard deviations.[1]

The revised HEI–2005 used to assess an individual's overall diet quality examines a multitude of influencing factors. Scores from HEI–2005 are calculated based on a 100-point scale comprising 12 major food components, and is summarized in table 2. Scores are assigned based on a density approach–that is, the standards for maximum scores are given as the amount of the food or nutrient per 1,000 calories (Guenther et al. 2006).

Higher HEI scores indicate closer adherence to current dietary guidelines for individual food and nutrient groups. For the adequacy components such as vegetables and fruits, a higher score indicates higher consumption, while for the last three components, saturated fat, sodium, and SoFAAS, a higher score indicates lower consumption.

Vitamin Supplement Intake

In light of declining fruit and vegetable consumption and rising levels of nutritional supplement intake in the United States, it remains unclear what role supplements may play in consumers' diet and health behavior. Many physicians advise the intake of multivitamin supplements because their patients might have difficulties consuming a balanced diet that includes a variety of fruits and vegetables (Wang 2011; Dooren 2011). The Dietary Guidelines for Americans 2010 suggests the consumption of fruit and vegetables for three main reasons: (1) they are major contributors of

[1] *In the original sample design of NHANES, the pseudo primary-sampling units (PSUs) are at the county level. To protect the identity of sample participants, these PSUs are aggregated into groups of secondary sampling units to create Masked Variance Units (MVU) so that users of the data can correctly estimate variances. To the extent that geographic region was included in the creation of the MVUs, we also control for regional variation when controlling for the complex sample design. Unfortunately, participant privacy precludes NHANES from releasing detailed information on the creation of the MVUs, or any additional geographic information. (Centers for Disease Control and Prevention 2006).*

Table 1. Definition and Descriptive Statistics of Variables

Variable	Definition	Mean (std. dev.)
Diet Quality		
HEI Total	Total HEI-2005 (Healthy Eating Index) over two days	51.60 (0.590)
HEI Fruit	HEI-2005 for total fruit over two days	2.15 (0.092)
HEI Vegetable	HEI-2005 for total vegetable over two days	3.01 (0.036)
Vitamin Supplement Intake		
Vitamins	=1 if intake of any vitamins, minerals, or dietary supplements during the past month	0.48 (0.01)
Lifestyle		
Very active	=1 if self-rated usual daily activity is doing heavy work or carrying heavy loads	0.35 (0.01)
TV	Number of hours the respondent watches TV per day	2.34 (0.07)
PC games	Number of hours the respondent used a computer past 30 hours a week	3.08 (0.12)
Smoker	=1 if respondent has smoked at least 100 cigarettes in entire life and is currently smoking every day or some days	0.25 (0.02)
Alcohol	=1 if female (male) respondents consumed on average 1 (2) alcoholic drinks or more of any type per day during the previous year	0.39 (0.01)
Health Indicators		
Waist circumference ratio	Ratio of the waist circumference to the cut-off for a healthy weight- 88 cm for females and 102 cm for males	1.04 (0.00)
Body Mass Index (BMI)	Weight (kg)/ $(\text{Height (m)})^2$	28.77 (0.19)
Cholesterol	Value is 1 if respondent has been told by a doctor or other health professional that blood cholesterol is high	0.24 (0.01)
Diabetes	Value is 1 if respondent has been told by a doctor or other health professional to have diabetes or sugar diabetes	0.07 (0.01)
Mental health	Number of days that mental health was not good during the past month	3.88 (0.25)
Physical health	Number of days that physical health was not good during the past month	3.31 (0.20)
Food Culture		
Food cost	Average 2-day cost of food consumed in U.S. dollars	9.98 (5.01)
Fast food	Percentage of daily calories a respondent consumes that were purchased in a fast food or pizza restaurant	15.07 (0.60)
Store	Percent of daily calories a respondent consumes that were purchased from a store	72.40 (0.61)
Immigrant	= 1 if respondent was not born in the U.S.	0.22 (0.03)
White	= 1 if respondent is non-Hispanic White	0.49 (0.05)
Black	= 1 if respondent is non-Hispanic Black	0.22 (0.03)
Hispanic	= 1 if respondent is Hispanic	0.25 (0.05)

Continued

Table 1. *Continued*

Variable	Definition	Mean (std. dev.)
Household size	=1 if household has between 3-6 members	0.62 (0.01)
Large household size	=1 if household has more than 7 members	0.06 (0.01)
Demographics		
Male	=1 if respondent is male	0.43 (0.01)
Age	Age of respondent in years	41.65 (0.65)
Some college	=1 if respondent attended some college	0.28 (0.45)
College	=1 if graduated college or above	0.29 (0.01)
Family income	Mean of each annual household income category in thousands per adult household member 4.9995 = Less than $10,000 12.4995 = Less than $15,000 ($10,000 to less than $15,000) 17.4995 = Less than $20,000 ($15,000 to less than $20,000) 22.4995 = Less than $25,000 ($20,000 to less than $25,000) 29.9995 = Less than $35,000 ($25,000 to less than $35,000) 39.9995 = Less than $45,000 ($35,000 to less than $45,000) 49.9995 = Less than $55,000 ($45,000 to less than $55,000) 59.9995 = Less than $65,000 ($55,000 to less than $65,000) 69.9995 = Less than $75,000 ($65,000 to less than $75,000) 87.5005 = $75,000 and more	43.71 (1.60)
Married	=1 if respondent is married or in a common-law relationship	0.69 (0.02)

Note: For the summary statistics we include the survey weights and control for NHANES' complex sample design in calculating the standard error. For variables that change between the two days, we present summary statistics for both days.

several under-consumed nutrients; (2) their consumption is associated with reduced risk of many chronic diseases; and (3) fruits and vegetables are naturally low in calories, which assists individuals in maintaining a healthy weight. Regarding the first reason, fruit and vegetables are major contributors of the shortfall nutrients folate, magnesium, potassium, dietary fiber, and vitamins A, C and K, of which potassium and dietary fiber are of particular concern to public health. Epidemiological studies have shown that vitamin deficiencies can contribute to severe health consequences such as cancer and cardiovascular disease (USDA/HHS 2010).

Consumers may choose to take nutritional supplements to *complement* and improve their diet with specific micronutrients. As such, vitamins might serve as a disease-preventative input. The U.S. Council for Responsible Nutrition suggests that up to $8.4 billion annually could be

Table 2. HEI Components and Range of Scores (Guenther et al. 2006)[1]

Component	Range of scores	Standard for maximum score[2]	Standard for zero score
Total Fruit (includes 100% juice)	0–5	$\geq$0.8 cup equiv.	No fruit
Whole Fruit (forms other than juice)	0–5	$\geq$0.4 cup equiv.	No whole fruit
Total Vegetables	0–5	$\geq$1.1 cup equiv.	No vegetables
Dark Green and Orange Vegetables and Legumes (Dry peas and beans)[3]	0–5	$\geq$0.4 cup equiv.	No dark green, orange vegetables or legumes
Total Grains	0–5	$\geq$3.0 oz equiv.	No grains
Whole Grains	0–5	$\geq$1.5 oz equiv.	No whole grains
Milk (all milk products and soy beverages)[4]	0–10	$\geq$1.3 cup equiv.	No milk products
Meat and Beans (meat, poultry, fish, eggs, soybean products other than beverages, legumes, nuts, and seeds	0–10	$\geq$2.5 oz equiv.	No meat or beans
Oils (non-hydrogenated vegetables oils and oils in fish, nuts, and seeds)[5]	0–10	$\geq$12 grams	No oil
Saturated Fat	0–10	$\leq$7% of energy[6]	$\geq$15% of energy
Sodium	0–10	$\leq$0.7 gram[6]	$\geq$2.0 grams[2]
Calories from Solid Fats, Alcoholic beverages, and Added Sugars (SoFAAS)	0–20	$\leq$20% of energy	$\geq$50% of energy

Notes: [1]*Intakes between the minimum and maximum levels are scored proportionately, except for Saturated Fat and Sodium (see*[5]*).*[2] *per 1,000kcal if not stated otherwise.*[3] *Legumes counted as vegetables only after Meat and Beans standard is met.*[4] *Includes all milk products such as fluid milk, yogurt, and cheese, and soy beverages.*[5] *Includes non-hydrogenated vegetable oils and oils in fish, nuts, and seeds.*[6] *Saturated Fat and Sodium get a score of 8 for the intake levels that reflect the 2005 Dietary Guidelines, <10% of calories from saturated fat and 1.1 grams of sodium per 1,000 kcal, respectively.*

saved if people consumed at least 100 International Units (IU) of vitamin E on a regular long-term basis to reduce the risk of heart disease (Bendich et al.1997; Dickinson 2002).

Other consumers may choose to consume vitamin supplements to *substitute* for the lack of consuming vitamins from fruits and vegetables. However, there might be insufficient evidence that the same protective effect of fruit and vegetables could be derived from dietary supplements (USDA/HHS 2010).

Dietary supplements are regulated by the U.S. Federal and Drug Administration (FDA) under the Dietary Supplement Health and Education Act (DSHEA). Under DSHEA, a firm is responsible for determining that the dietary supplements it manufactures or distributes are safe (U.S. Food and Drug Administration 2011, Denham 2011). Studies suggest that dietary supplement manufacturers may actually encourage consumers to substitute their physician-prescribed medications with supplements. Thus, at-risk populations may be more prone to consuming dietary supplements given that consumers may not be able to differentiate between technical descriptions and marketing language (U.S. Government Accountability Office [GAO] 2011). Given the available definition in NHANES 2003-2004, vitamin supplement intake was measured as a binary variable, which indicated whether the respondent took any vitamins, minerals, or dietary supplements during the past month.

Lifestyle

Lifestyle indicators include health and risk behaviors such as exercise frequency and sedentary activities such as time spent in front of the TV and/or computer, smoking, and frequent alcohol consumption. These lifestyle factors may significantly influence an individual's health status and food choice behavior (Cawley and Ruhm 2011). Health experts continue to emphasize the importance of regular health-enhancing activities, including the consumption of a well-balanced diet and physical activity (Dwyer 2001; USDA/USHHHS 2010). It is plausible to assume that time spent exercising may be positively correlated with eating a healthy diet. In our sample, exercise frequency has been classified into three groups depending on an individual's average daily level of activity. Non-work or study-related screen time means less time for physical activity, which may indicate that the respondent values sedentary entertainment over the health benefits of physical activity. Increased screen time may also be a proxy for unhealthier food or snack choices.

Nicotine, an appetite suppressant, has been associated with increased risk of developing lung cancer, emphysema and heart conditions. Huston and Finke (2003) suggest that smokers tend to prefer present utility gains compared to their future health status and longevity. Smokers also have been shown to have lower levels of diet quality (Ma et al. 2000). *The Dietary Guidelines for Americans 2010* recommends that women consume no more than one alcoholic drink per day, and men no more than two. However, the impact of alcohol on diet quality is ambiguous. Red wine in moderation has been linked to good health, but drinking more than three alcoholic drinks per day has been shown to increase the likelihood of injuring oneself or others, liver conditions, mental health problems and numerous other health problems (Klatsky 2010).

Health Indicators

Health indicators should be understood as a marker for the individual's current health status. Longitudinal studies directly link poor diet quality to deteriorating health indicators such as obesity, cholesterol levels, type 2 diabetes, and overall physical health, which in turn are all indicators of a higher risk of cardio-vascular disease (Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults 2001; USDA/HHS 2010). We model health indicators based on respondent's reported health status, rather than NHANES' medical exam results. We assume that with an individual's unawareness about her/his own health status, diet behavior would not be changed to counteract the condition.

Obesity has been at the center of the diet-health policy debate in the United States, and the focus of a growing number of economic studies (e.g. Frazão and Allshouse 2003; Park and Davis 2001). We employ two alternative measures to capture the impact of past eating behavior on HEI. The ratio of measured waist and the cut-off point for obesity, 88 cm for women and 102 cm for men (National Institute of Diabetes and Digestive and Kidney Diseases 2004), and the standard Body Mass Index (BMI) are both measures of past eating behavior.

In addition, we use binary variables to reflect whether an individual has been told by a health professional that their blood cholesterol is high or that the individual has diabetes. The variables mental health and physical health are self-measured and indicate the number of days per month in which a respondent felt their health status was not good. Despite its subjectivity, previous research suggests that self-rated health status is a valid predictor of issues such as physical functioning in the adult population (e.g. Goodwin et al. 2006; Goldstein et al. 1984).

Food Culture

Food culture, a relatively new construct, encompasses measurable factors that describe taste preferences, food choices and familiarity with foods (Carlson et al. 2010). We built on this concept to capture a participant's food choice and consumption patterns that can be ascribed to differences in ethnicity, heritage, and family structure. As such, food culture includes factors over which the individual has complete control (e.g. location of food purchase such as restaurant, fast food establishment, or grocery store), and factors the individual is unlikely to change to improve their diet quality (e.g. household size). Household size is also included to capture differences in food culture at home, as larger households may be more likely to cook more often than smaller size or single households.

Other elements of food culture over which the individual has no control include immigration or citizen status, heritage and ethnicity. These are indicators of the types of foods and/or traditional consumption patterns the individual has been exposed to over a long period of time. Eating habits formed during childhood have been shown to have a lasting impact on adult food habits (Becker 1992; USDA/HHS 2010). In contrast, Aldrich and Variyam (2000) argue that as the U.S. population becomes more diverse and many individuals live in or grow up in multi-racial settings, race and ethnicity may play a less important role with regard to diet quality. A well-documented case in point emphasizing the interplay of diet quality and ethnicity is the "Hispanic Health Paradox." The paradox suggests that U.S. immigrant's heritage food culture may act as a protective barrier against a rapid assimilation of dietary habits. This may lead to health outcomes that are equal to or better than those of non-immigrants, despite higher poverty rates, lower education and worse access to health care among many Hispanic immigrant groups living in the United States (Morales et al. 2002; Batis et al. 2011). Other research has shown that even though immigrants are in better health upon arrival to the United States compared to their U.S.-born counterparts, this health advantage erodes over time (Antecol and Bedard 2006).

Food Cost

Although U.S. consumers spend a relatively small share of their income on food – currently about 11% of disposable income (USDA/ERS 2011) – the cost of food is one of many factors that may affect some purchase decisions, though generally not the leading factor (Wansink 2004). Since the NHANES does not collect information on food prices or expenditures, we use the 2003 – 04 Center for Nutrition Policy and Promotion's (CNPP) Food Prices Database to calculate the prices of food in its consumed form (Carlson et al. 2008; USDA/CNPP 2009). Given that these are national average prices, they do not contain any regional variation, and thus the prices do not necessarily reflect the exact retail prices paid by an individual. The CNPP price estimates account for the food purchased and potential losses due to preparation (peels, seeds, shells, bones and skins) or gains and losses through cooking (moisture and fat loss and gain). The Food Prices Database does not include alcohol in any food (e.g. wine in a sauce) or drink. When creating the database, any alcohol that was in a food was converted to a nonalcoholic alternative (e.g. fruit juice) and priced accordingly. Because of this conversion, the true cost of a daily diet may be slightly underestimated when priced with CNPP prices. However, this would only impact the cost of the SoFAAS component of the HEI, which only comprises 20% of the total HEI score. Since alcohol typically comprises a very small proportion of the total diet for most people, the use of the CNPP price data can be expected to only marginally affect the quality of the analysis in this study.

Given that CNPP food prices only reflect the cost of foods prepared at home, an upward cost adjustment for foods purchased away from home is required. This adjustment is based on a comparison of the estimated mark-up for food at home and food away from home (Carlson et al. 2010). We use an adjustment factor of 1.4 – 2, depending on the type of establishment (e.g. fast food, deli, table service, recreation facility, and non-school cafeteria). To estimate daily total cost, prices are attached to the daily consumption of foods and non-alcoholic beverages, which are then summed up (Carlson et al. 2010).

As table 1 shows, the average 2-day food cost of 2003 – 04 NHANES participants is $9.98. The weekly cost for 20 – 50 year old males is $32.70, and females $29.70, which translates to an average daily cost of $4.46, and a two-day cost of $8.91. The amount found in this study is just slightly higher than the USDA's Thrifty Food Plan for males and females during June 2004, which indicates that the individual should be able to purchase a healthy diet (Lino 2011). However, the CNPP national average food prices, which are the only consistent measure of "food cost" for NHANES respondents, may not necessarily reflect a household's true food expenditures, and has been shown to underestimate actual expenditure levels.

Demographics

Several demographic variables may impact the consumption of fruits and vegetables, such as gender, age, education, income, and marital status. Previous studies have shown that the consumption of fruits and vegetables is typically lower among men compared to women (e.g. Variyam et al. 1998; Arnade and Gopinath 2006; CDC 2007; Beydoun and Wang 2008; Stewart and Blisard 2008; Todd et al. 2010). With increasing age, people tend to eat a diet of higher quality that contains less energy, since the benefits of health and good nutrition may become more apparent (Frazão and Allshouse 2003). Reported dietary supplement intakes have been consistently higher, particularly among older consumers (Dickinson and Shao 2006). In addition, the metabolic rate slows down with growing age, and therefore the body does not require as many calories to maintain its weight (Myers 2003). Education, a proxy for knowledge, information, and awareness of healthy practices, as well as a willingness to invest in long-term outcomes (Huston and Finke 2003) may lead to overall higher diet quality, and is assumed to have a strong positive impact on HEI. In addition to age, gender, and education, we classify respondents into three income groups to capture the association between income and diet quality emphasized by previous economic analyses of diet and health (Mancino et al. 2004; Bogue et al. 2005; Petrovici and Ritson 2006). Moreover, Jeffrey and Rick (2002) found marriage to be associated with higher consumption of calorie-dense foods and lower frequency of exercise.

Analysis

The estimation of the determinants of an individual's diet quality, HEI_i, in equation (1) faces a challenge frequently discussed in health behavioral studies based on cross-sectional population data – the likely endogeneity of nutrition and health variables and related misspecification of empirical models (e.g. Park and Davis 2001; Doh and Nayga 2007).

In this study, these issues evolve around the potential endogeneity between diet quality and the intake of vitamin supplements. After formally testing and confirming endogeneity between V_i and HEI_i, the instrumental variable equation for vitamin supplement intake is represented as:

$$V_i = \gamma Z_i + \mu_i \tag{2}$$

where Z is a vector of instruments, γ is an estimateable parameter and μi is the error term.

The standard econometric method in the literature for estimating equations (1) and (2) are two-stage least squares estimators that rely on the assumption that appropriate instruments are available.

However, the difficulty of finding suitable instruments for cross-sectional analyses of nutrient intake and health behavior data has been raised by several studies (Subramanian and Deaton 1996; Park and Davis 2001; Abdulai and Aubert 2004). While suitable instruments that are sufficiently highly correlated with the variable of interest and uncorrelated with the error term are often unavailable, using inappropriate instruments may severely bias instrumental variable estimators and may produce results that are inferior to OLS estimates.

To avoid the problem of unsuitable instruments regarding the endogeneity of vitamin supplement intake in diet quality, we adopt the approach originally proposed by Lewbel (1997) and further developed in Lewbel (2006; 2012) for creating additional, and as Lewbel proves, suitable instruments. In particular, Lewbel's identification strategy, unlike in conventional instrumental variable estimators, relies on a vector of model regressors that are uncorrelated with the covariance of heteroscedastic regression errors. As shown by Lewbel, identification can be achieved without any exclusion restrictions, and α_1 (in equation 1) can be consistently estimated based on existing exogeneous variables in the structural equation and errors that are heteroskedastic. In the first stage, the endogeneous variable (*Vitamins*) is regressed on all control variables X deemed exogenous in the HEI equation along with the Z vector of defined instrumental variables. According to Lewbel (2006), suitable candidates for the Z vector are variables that might alternatively be used as instruments in the given context.

Thus, for the analysis of diet quality, we consider a subset of variables (X_i) presented in table 1 to be sufficiently exogenous (i.e. gender, education, race, immigration status, and household size). These estimated residuals can then be used to construct higher order instruments of the form $(Z_i - \bar{Z})\hat{e}_2$, where $\hat{e}_2$ are the estimated residuals from equation 2. Several empirical applications have since exploited heteroskedasticity for identification following Lewbel's approach, as summarized in Lewbel (2012).

The newly-created IV model can be estimated by 2SLS or GMM, and common tests to verify instrument validity and exogeneity can be applied. Building on Lewbel's approach, we specify three empirical models to address the role of vitamin intake on different diet quality measures in NHANES.

In the first specification, three Healthy Eating Index scores (HEI), total HEI, HEI fruits, and HEI vegetables are regressed against selected key lifestyle, health indicators, and food culture and demographic variables. We call this specification our "Full Model". The total HEI captures the overall impact of vitamin supplement intake on diet quality among NHANES participants. The fruit and vegetable component scores address the question of whether vitamin supplement intake serves to complement the consumption of a recommended diet that includes fruits and vegetables, or whether supplement intake serves to substitute for these recommended sources of nutrients in a population already failing to meet or even ignoring nutritional guidelines.

$$\begin{aligned} HEI_{T,F,V} = f\,(&Vitamins, Very\ active, Waist\ circumference\ ratio, Fast\ food, \\ &Store, Immigrant, White, Black, Hispanic, Medium\ household, \\ &Large\ household, Age, Some\ college, College, Family\ income, Married) \end{aligned} \tag{3}$$

Economic studies of diet and health behavior have frequently identified at-risk populations as the target groups for nutrition and health policy intervention in the United States. We specify a second set of empirical diet quality equations, our "At-risk Model", to estimate the impact of vitamin intake on diet quality when controlling for critical lifestyle factors and indicators of existing health conditions. In this second model, these variables are regressed against the three HEI scores of interest:

$$HEI_{T,F,V} = f\big(Vitamins, TV, PC\ games, Smoker, Alcohol, BMI, Cholesterol, Diabetes, Mental\ health, Physical\ health, Food\ cost, Male\big). \tag{4}$$

The At-risk Model specification includes variables commonly associated with low socio-economic status and poor lifestyle. Additionally, we incorporate health indicators that have been associated with poor compliance with dietary guidelines and the rise in secondary chronic health problems such as sedentary activities, smoking and drinking, elevated blood cholesterol and BMI, diabetes, and mental and physical health indicators.

We controlled for complex sample design by using the survey estimation commands in Stata when estimating both the full and at-risk models. We estimated each model specification and HEI score using two IV methods, standard 2SLS and alternative GMM estimators, each employing secondary and tertiary instruments following Lewbel's (1997; 2012) approach.

Results

Tables 3 and 4 show the IV coefficient estimates from the full and at-risk model specifications for the three selected diet quality measures: Total HEI-2005, and the Fruit and Vegetable component scores. Overall, the coefficient estimates show robustness and only minor differences across the IV estimation method.

In addition to the variable of interest, *Vitamins*, other independent variables may be considered endogenous. To establish model validity and exogeneity of the chosen explanatory variables, we conduct a series of test statistics. First, to confirm the validity of Lewbel's (2012) identification strategy, we test for the presence of heteroskedasticity using Pagan and Hall's (1983) test, a necessary condition for model identification. The results show that the null hypothesis of homoscedastic errors is rejected in all models with p-values equal to 0.000. Second, to test for the endogeneity of individual regressors we conduct a series of C-tests to establish exogeneity (orthogonality of the instrument in question). Of all exogenous explanatory variables across the six HEI model specifications, four variables pass the test of exogeneity at the 10% level. These variables are: Hispanic in the HEI Total model; Diabetes in the HEI Fruits At-risk model; and Food cost in the At-risk models of HEI Vegetables and HEI Fruits. All other variables prove clear exogeneity at the 5% level or higher. Third, to confirm the validity of the chosen instruments we report Sargan and J-tests of overidentifying restrictions as a measure of instrument validity. Both tests support the validity of our chosen instrumental variables and indicate proper model specifications.

NHANES respondents who consume vitamin supplements have significantly higher levels of total HEIs. This is an interesting result, because it suggests that consumers of a well-balanced diet care enough about their health to also take vitamin supplements. In this case, vitamin

Table 3. Full Model Results

	HEI Total		HEI Fruit		HEI Vegetable	
Variable	**GMM**	**2SLS[a)]**	**GMM**	**2SLS[a)]**	**GMM**	**2SLS[a)]**
Constant	36.172***	37.123***	-0.229	0.238	2.444***	2.448***
	(20.55)	(19.73)	(-0.83)	(0.86)	(11.96)	(16.51)
Vitamin supplement intake						
Vitamins	3.284***	3.299***	0.467***	0.466***	0.136**	0.133***
	(8.25)	(8.93)	(7.62)	(8.35)	(2.88)	(4.13)
Lifestyle						
Very active	1.797***	1.811***	0.161**	0.164**	0.140***	0.138***
	(4.78)	(5.77)	(2.85)	(2.67)	(3.25)	(3.41)
Health indicators						
Waist circumference ratio	2.471**	2.496**	0.366**	0.371**	0.337**	0.339***
	(2.36)	(2.33)	(2.27)	(2.58)	(2.72)	(3.00)
Food culture						
Fast food	-0.083***	-0.083***	-0.012***	-0.012***	-0.003**	-0.003***
	(-6.83)	(-10.85)	(-6.33)	(-5.82)	(-2.14)	(-3.49)
Store	0.059***	0.059***	0.006***	0.006**	-0.003**	-0.003***
	(6.13)	(5.84)	(4.83)	(2.66)	(-2.80)	(-3.32)
Immigrant	6.641***	6.677	0.777***	0.777***	0.382***	0.384***
	(12.03)	(11.04)	(9.24)	(8.34)	(6.19)	(5.10)
White	-1.482	-1.444	-0.071	-0.074	-0.137	-0.134
	(-1.52)	(-1.51)	(-0.49)	(-0.56)	(-1.26)	(-1.44)
Black	-2.287**	-2.285**	0.132	0.134	-0.381***	-0.392***
	(-2.22)	(-2.23)	(0.86)	(1.20)	(-3.29)	(-4.08)
Hispanic	0.373	0.399	0.155	0.152	-0.158	-0.159
	(0.38)	(0.35)	(1.04)	(1.18)	(-1.44)	(-1.35)

Continued

Table 3. *Continued*

Variable	HEI Total		HEI Fruit		HEI Vegetable	
	GMM	**2SLS[a)]**	**GMM**	**2SLS[a)]**	**GMM**	**2SLS[a)]**
Medium household size	-0.846**	-0.847	-0.039	-0.40	-0.098***	-0.097*
	(-2.10)	(-1.64)	(-0.63)	(-0.76)	(-2.06)	(-1.80)
Large household size	-1.376	-1.385	0.050	0.049	-0.184*	-0.184*
	(-1.59)	(-1.01)	(0.35)	(0.23)	(-1.80)	(-1.76)
Demographics						
Age	0.112***	0.112***	0.016***	0.016***	0.008***	0.008***
	(10.34)	(6.92)	(9.90)	(6.90)	(5.82)	(6.93)
Some college	1.397***	1.393***	0.144**	0.142**	0.063	0.061
	(3.27)	(3.21)	(2.22)	(2.44)	(1.25)	(1.53)
College	4.979***	4.976***	0.564***	0.562***	0.260***	0.259***
	(9.20)	(11.00)	(7.06)	(9.22)	(4.31)	(5.28)
Family income	0.016**	0.0158*	0.002	0.002	0.002**	0.002**
	(2.09)	(1.96)	(1.53)	(1.47)	(2.27)	(2.83)
Married	0.445	0.439	-0.045	-0.046	0.132***	0.131**
	(1.16)	(0.71)	(-0.78)	(-0.62)	(2.91)	(2.62)
Number of observations	4,030					
Adj. R^2 (1. stage)	0.22 (0.88)	0.22	0.15 (0.67)	0.15	0.064 (0.86)	0.064
Hansen J-test (GMM)	1.43 (0.49)		2.18 (0.34)		2.75 (0.26)	
Sargan test (2SLS)	1.26 (0.26)		2.59 (0.28)		1.75 (0.42)	

Table 4. At-Risk Model Results

	HEI Total		HEI Fruits		HEI Vegetables	
Variable	**GMM**	**2SLS[a)]**	**GMM**	**2SLS[a)]**	**GMM**	**2SLS[a)]**
Constant	52.908***	52.900***	2.583***	2.580***	2.177***	2.178***
	(74.65)	(73.79)	(23.30)	(22.12)	(25.41)	(28.62)
Vitamin supplement intake						
Vitamins	4.141***	4.139***	0.489**	0.490***	0.334***	0.333***
	(12.93)	(13.01)	(9.95)	(8.83)	(9.09)	(11.36)
Lifestyle						
TV	-0.567***	-0.568***	-0.066***	-0.066***	-0.038***	-0.038***
	(-6.31)	(-6.43)	(-4.85)	(-3.63)	(-3.70)	(-4.48)
PC games	0.102*	0.103*	0.187**	0.187*	0.015**	0.015*
	(1.83)	(1.86)	(2.18)	(1.87)	(2.36)	(2.07)
Smoker	-4.876***	-4.871***	-0.685***	-0.685***	-0.133***	-0.134**
	(-11.78)	(-11.38)	(-10.81)	(-9.28)	(-2.62)	(-2.52)
Alcohol	-2.112***	-2.114***	-0.267***	-0.265***	0.046	0.045
	(-5.79)	(-5.72)	(-7.78)	(-4.85)	(1.09)	(1.33)
Health indicators						
Body Mass Index	-0.025	-0.024	-0.006	-0.006**	0.014***	0.014***
	(-1.13)	(-1.10)	(-1.64)	(-2.18)	(5.13)	(7.58)
Cholesterol	3.444***	3.446***	0.307***	0.308***	0.340***	0.337***
	(8.97)	(9.20)	(5.25)	(4.58)	(7.91)	(6.67)
Diabetes	4.351***	4.357***	0.380***	0.382***	0.180***	0.180***
	(6.99)	(7.64)	(4.19)	(3.35)	(2.61)	(3.53)

Continued

Table 4. *Continued*

	HEI Total		HEI Fruits		HEI Vegetables	
Variable	**GMM**	**2SLS[a)]**	**GMM**	**2SLS[a)]**	**GMM**	**2SLS[a)]**
Mental health	-0.132***	-0.132***	-0.017***	-0.017***	-0.008***	-0.008***
	(-6.42)	(-6.39)	(-5.57)	(-5.45)	(-3.35)	(-3.22)
Physical health	-0.011	0.011	0.002	0.002	-0.000	-0.000
	(-0.52)	(0.53)	(0.61)	(0.54)	(-0.06)	(-0.02)
Food culture						
Food cost	0.044	0.044	0.005	0.005	0.031***	0.031***
	(1.49)	(1.52)	(1.00)	(1.17)	(8.96)	(10.60)
Demographics						
Male	-2.088***	-2.087***	-0.326***	-0.325***	-0.258***	-0.258***
	(-6.99)	(-7.07)	(-7.14)	(-6.42)	(-7.50)	(-8.24)
Number of observations	6,187					
Adj. R^2 (1. stage)	0.12 (0.95)	0.12	0.08 (0.66)	0.08	0.07 (0.83)	0.07
J-test (GMM)	0.08 (0.96)		4.40 (0.36)		5.55 (0.24)	
Sargan test (2SLS)	0.08 (0.96)		4.41 (0.36)		5.71(0.22)	

consumption seems to serve as another marker for healthy eating. As expected, NHANES respondents who already follow a "very" physical active lifestyle score 1.8 points higher in term of their total HEI. The same relationship holds for diet quality in fruit and vegetable intakes, respectively.

Against the common belief that people of poor diet-related health status eat unhealthy diets, the results of the full model (table 3) indicate that the health indicator "waist circumference ratio" is positively correlated with increases in total diet quality. To verify validity of this coefficient estimate, we re-estimated the model without this health indicator. All model results proved to be robust, and a suspected endogeneity of the variable waist circumference ratio was soundly rejected.

The food culture variables show interesting results that confirm previous findings. Previous research has argued that food consumed away from home is a contributor to poor diet quality (Mancino et al. 2009). We find that individuals who purchased a higher percentage of their calories (over a two-day period) at fast food and pizza restaurants had a lower total HEI score by 0.8 points, 0.12 points for fruit and 0.03 points for the vegetable HEI. Individuals who purchased more foods at stores had higher total and HEI fruit scores than individuals who purchased food at non-fast food restaurants. This finding confirms that typically, store-bought food for at-home consumption tends to be of higher diet quality (Lin, Guthrie, and Frazão 1999). Interestingly, store-bought food purchases are negatively associated with the HEI vegetable component score, which confirms the intricacy of food environmental factors that affect consumer produce choice. In particular, the number of supermarkets in an individual's neighborhood or size of the grocery store may influence access to produce. Compared to supermarkets, smaller neighborhood stores mostly stock processed foods and some fruit, but rarely any vegetables (Glanz et al. 2007).

Being an immigrant significantly increases total diet quality by 6.4 points. A U.S. immigrant's heritage food culture indeed seems to act as a protective barrier against the adoption of "unfavorable" U.S. dietary habits by maintaining traditional cooking and eating practices. This finding confirms previous literature (Morales et al. 2002; Batis et al. 2011). This protective barrier might only be temporary, given that it has been shown that on average, female (male) immigrants converge within 10 (15) years to the U.S. BMIs (Antecol and Bedard 2006).

Only respondents of black ethnic background have significant lower total diet quality (2.3 points) and lower HEI vegetable (0.39 points) when compared to other ethnic groups. White and Hispanic participants did not have significantly different diet qualities compared to the "other" group, which includes Asian, mixed, Native American and Pacific Island.

Household size significantly impacts diet quality. However, the magnitude, size, and significance of these effects differ by the number of household members. This finding supports the consideration of the two separate variables, medium vs. large households. Overall, medium households impact HEI scores negatively. Both medium and large households show negative impacts on the HEI vegetable component score, even though the effects for medium households are smaller in magnitude. Our findings suggest that larger households – those of lower income status – may face food budget constraints in following dietary recommendations.

In conjunction with a positive effect of income on the overall HEI and HEI vegetable component scores, large households are associated with lower HEI vegetable scores.

As expected from our demographic variables, diet quality improves with increasing age. College-level education has a strongly positive effect (5 points) on overall diet quality. Marital status does little in terms of improving diet quality, but does a positive impact on the vegetable HEI by 0.13 points.

Our At-risk model specification (table 4) reveals a significant positive impact of vitamin supplement intake on diet quality of NHANES respondents who reported at least one of several at-risk attributes. For at-risk individuals, vitamin supplement intake is correlated with an increase in diet by 4.1 points, compared to 3.2 points in the full model.

With regard to lifestyle, our results show that sedentary behavior, for example hours spent watching TV, contributes to lower diet quality. Playing video games shows a positive yet marginal relationship to all three measures of diet quality. Since we controlled for physical activity, this may suggest that the negative relationship between TV watching and diet quality does not carry over to playing video games.

As expected, smokers have significantly lower HEI scores, and so do individuals who consume alcohol at or above the acceptable daily intake levels. Like smoking, excessive alcohol consumption has been associated with diminished levels of interest in long-term health. Males comprise a population at-risk of poor diet behavior and resulting health consequences. Special focus was given to health indicator variables in the at-risk respondent group. Respondents with a higher score in the HEI vegetables showed increased BMI levels, which confirms the findings in the full model. Lifestyle factors have a strong influence on diet quality, which confirms previous studies (Ma et al. 2000; Dwyer 2001; Klatsky 2010). Particularly smoking, time spent watching TV, and consuming increased levels of alcohol impact the diet quality of at-risk respondents negatively.

Individuals diagnosed with diabetes or elevated blood cholesterol levels show higher HEI scores. Both health indicators reflect conditions that could develop from a history of poor diet behavior, and patients are typically advised to increase their consumption of fruits and vegetables as part of other educational as well as therapeutic measures. Even though these findings appear to contradict the hypothesis of a negative relationship between a diet-health condition and diet quality, the results are robust with regard to the model specification and prove significantly exogenous in determining an individual's HEI score. Given the cross-sectional nature of this analysis, our results suggest that previously diagnosed health conditions may have triggered changes in an individual's diet behavior. Thus, our estimates should be interpreted as a contribution to the understanding of the relationship between health status and diet behavior, which is an issue of frequent debate in the health economics literature. In contrast, individuals with diagnosed mental or physical health issues form an at-risk group with poor diet quality patterns. To our knowledge, little economic research has been conducted on investigating diet behavior among mentally or physically compromised individuals.

The cost of food was explicitly considered in the at-risk model to account for the possible effect of food budget constraints faced by low-income respondents on diet quality. Food cost does not affect diet quality, which confirms previous research (e.g. Carlson et al. 2010). In fact, food cost did not produce significant results in the full model and was subsequently dropped from this group of models.

Conclusions

This study provides a unique contribution to the literature on a key food-health policy issue. We examine the relationship between declining produce consumption, rising intake of vitamin supplements, and diet quality. In light of decreasing levels of fruit and vegetable intake and increasing demand for nutritional supplements, the ability to self-medicate using a range of vitamin supplements without any control mechanism has been raised as a key public health concern (De Jong et al. 2003).

We hypothesized a substitutive relationship between vitamin supplement and fruit and vegetable consumption. Our findings demonstrate the significant interaction between the total diet quality of U.S. consumers and the intake of vitamin supplements. However, consumers do not substitute fruit and vegetable consumption with vitamin supplements, which is shown by a small, albeit significant interaction between a high fruit and vegetable HEI and vitamin supplement consumption. The results of our model specification emphasizes that lifestyle factors, health indicators and food culture are important covariates that, together with vitamin supplement intake, have a significant impact on U.S. consumers diet quality outcomes. The 2010 Dietary Guidelines for Americans state that at-risk population groups may be in need of supplements to meet minimum dietary recommendations, which supports the need for a targeted approach for improving the diets of at-risk populations (USDA/HHS 2010; Balluz et al. 2000). We confirm that individuals who already lead a healthy lifestyle are likely to consume dietary supplements (Radimer et al. 2000; Greger 2001).

This finding supports nutritional recommendations and existing research evidence regarding the health benefits of regular vitamin supplement intake (Bendich et al.1997; Dickinson 2002). However, it also suggests that healthy eaters may not need to supplement their diets, which may lead to a potential vitamins and/or mineral intake above the recommended upper levels (USDA/HHS 2010). In short, the evidence produced by the NHANES respondents suggests that vitamin supplements may not be consumed as a substitute for fruit and vegetable intake. Given the techniques used in our health economic study, supplement use should be discouraged for the general population given that they may be harmful.

These findings contribute to the ongoing discussion about the regulatory issues of dietary supplements and their implications for public health. While vitamins might serve as a disease-preventative input that supplement a poor diet for at-risk consumers, it is important to assess the safety and efficacy of dietary supplements. As such, DSHEA might need to be improved or reformed to prevent consumers with serious medical conditions from either relying on products with no medicinal value or from consuming amounts that are harmful to their health. At a minimum, consuming supplements in addition to a healthy diet is also wasteful. Thus, there may be a need for regulations that are efficacious and formulated for legitimate ends (Denham 2011).

In this study, we expand on the conclusions by Park and Davis (2001) and Variyam et al. (1999) regarding the need for greater attention to the correct specification and performance of alternative IV estimators. This is necessary to avoid spurious results commonly encountered in analyses of cross-sectional studies of diet behavior. To address issues of endogeneity and misspecification, we implement an instrumental variable identification technique developed by Lewbel (2006; 2012) that uses heteroskedastic errors as the only exclusion restriction in creating higher-order instruments. The results from the identification using alternative 2SLS and GMM estimators yield similar parameter estimates. Thus, this technique delivers robust evidence regarding the relationship between vitamin supplement intake and the diet quality of U.S. consumers. In contrast to previous studies that have relied on Lewbel's (1997) original, and since-criticized instrumental variable approach (Erickson (2001), we use Lewbel's (2006; 2012) more recently developed estimator, which exploits heteroskedasticity for model identification and does not rely on any exclusion restrictions. We find all selected Lewbel instruments to be relevant and sufficiently exogenous, performing above simpler OLS estimators.

Finally, the potential efficiency advantages of GMM over 2SLS IV estimators discussed by Baum et al. (2003) did not materialize in this analysis. Regarding the reliability of IV estimation methods in the analysis of cross-sectional and health-behavioral data, we confirm that strong exogenous instrumental variables are of high importance to the validity of empirical results, and hence policy recommendations derived from such studies.

Dietary supplements are a major area of industry growth and competition for the U.S. food sector. Yet this topic has received little attention in applied economics research to date. An aging population, retiring baby boomers and increased awareness of diet-health related disease (e.g. obesity, diabetes) all pose challenges to public health. The so-called "diet-health mega-trend" is expected to push the future demand for vitamin supplements that might provide health benefits. In addition, there might be additional market pressure for convenient product innovations from the fruits and vegetable sector.

Our empirical results contribute to developing a better understanding of factors that impact diet-health behavior and provide insight to researchers, industry and policy stakeholders with regard to the more efficient promotion of preferred nutritional food choices and targeted education.

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