The Australian Journal of
Agricultural and
Resource Economics

Journal of the Australian Agricultural and Resource Economics Society

The Australian Journal of Agricultural and Resource Economics, 57, pp. 301–319

Consumer demand for diet quality: evidence from the healthy eating index*

Zhifeng Gao, Xiaohua Yu and Jonq-Ying Lee†

Few studies have been performed to use the detailed healthy eating index (HEI) to estimate consumer demand for diet quality. In this article, we apply household production theory to systematically estimate consumer demand for diet quality using the HEI developed by the U.S. Department of Agriculture. The results show that consumers have insufficient consumption of food containing dark green and orange vegetables, legumes and whole grains. Age and education have a significant impact on consumer demand for diet quality, but income does not. The own-price elasticities of demand for diet quality are inelastic. Simulation of tax scenarios indicates that a tax on sugar-sweetened beverage may be more efficient than a tax on fats, oils and salad dressing in improving consumer diet quality. This information is critical for policies and programs that are designed to improve healthy food choices, thereby reducing the social cost of public health.

Key words: demand, diet quality, healthy eating index, translog cost function.

1. Introduction

Promoting a healthy diet has become a global priority because of the scientific linkage between food intake and human health. For instance, in Australia, the Commonwealth Department of Health and Ageing has developed the Australian Guide to Healthy Eating and promotes programs such as the Stephanie Alexander Kitchen Garden National Program to encourage healthy food consumption. In the United States, the U.S. Department of Agriculture (USDA) developed the new MyPyramid food guidance system in 2005 to help consumers make healthy food choices. Based on the 2005 Dietary Guidelines for Americans[1] (2005 DGA), the USDA revised the Healthy Eating Index (HEI) to measure diet quality (Guenther *et al.* 2008). Countries such as Denmark and France started to use taxes such ‘fat tax’, ‘junk food tax’ and ‘sweetened drink tax’ to motivate healthy food consumption.

However, a gap may exist between nutritional studies on diet and economic analysis of demand for a healthy diet (diet quality[2]). Most literature on nutrition and diet has focused on determinants of nutrient and dietary intakes

* We would like to thank the editor, associate editors as well as the two anonymous reviewers, for their comments on earlier drafts of this article.

† Zhifeng Gao (email: zfgao@ufl.edu) and Jonq-Ying Lee are with the Food and Resource Economics Department, University of Florida, Gainesville, Florida, USA. Xiaohua Yu is at Courant Research Centre – PEG, University of Göttingen, Göttingen, Germany.

[1] The Department of Health and Human Services and the Department of Agriculture have jointly published the Dietary Guidelines for Americans every 5 years since 1980. The newest 2010 Dietary Guideline for Americans was released in January 2011.

[2] In this article, we refer to diet quality as healthy status of a diet.

doi: 10.1111/j.1467-8489.2012.00619.x

and the impact of diet on consumer health (Eastwood *et al*. 1984; Vining 2008); on evaluation of dietary quality using indices such as the HEI (Schmidt *et al*. 2005; O'Neil *et al*. 2010); and on determinants of the relationship between diet cost and quality (Drewnowski and Darmon 2005; Lo *et al*. 2009). Economic studies extensively focus on consumer demand for foods such as fruits and vegetables (FV), meats, beverages (Heien and Pompelli 1989; Brown *et al*. 1994). Some economic studies of diet quality use food diversity as a proxy for diet quality (Lee 1987; Thiele and Weiss 2003). Although food diversity is related to diet quality, it may not be as good a measurement as the HEI that is based on dietary guidelines. Studies that investigate the linkage between cost and diet quality (Cade *et al*. 1999; Lo *et al*. 2009; Duffey *et al*. 2010) include limited food products in their cost calculations.

The fact that there are few studies addressing consumer demand for diet quality is likely due to inadequate measures of diet quality and the unavailability of food prices. The HEI, initially developed in 1995, was updated in 2006 based on 2005 DGA. However, it was not until 2009 that the Center for Nutrition Policy and Promotion (CNPP) of the USDA published the Food Price Database (FPD) of food products in 'as consumed' forms for 2003–2004 (USDA-CNPP 2009). The food products in the database match those reported by respondents in the National Health and Nutrition Examination Surveys (NHANES) on Dietary Interview-Individual Foods (DIIF) and Dietary Interview-Total Nutrient Intakes (DITN) (CDC 2007). This information enables us to estimate the cost of accessing a food product in different food groups and consumer demand for diet quality.

This article contributes to the current literature from four aspects: (i) we use the household production theory to develop a theoretical framework to study consumer demand for diet quality; (ii) we empirically estimate the diet cost function by imposing theoretical properties, which is essential for obtaining proper demand elasticities; and (iii) we estimate consumer demand for the diet quality of the 12 diet groups that make up the total diet. The segregated estimation of the demand provides more useful information for the development of relevant policies and programs to promote healthy diet. In addition, we studied the impacts of taxes on two different food groups on diet quality. The approach used in this article can be applied to similar data in other countries.

2. The healthy eating index

The HEI was developed to evaluate the healthy status of the diet of adults aged 2 years and older. It consists of individual indices of 12 diet groups[3]

[3] We distinguish diet group from food group in this article. The diet group is defined based on the nutritional values of food for which the HEI is calculated. The food group is defined based on the market classification of the food. For example, ginger is classified as a vegetable in the market; however, based on the classification of diet group, it does not belong to any vegetable diet group. This is because ginger does not provide any nutrition like that provided by other vegetables.

such as TOTAL FRUIT, WHOLE FRUIT, TOTAL VEGETABLES, DARK GREEN & ORANGE VEGETABLES & LEGUMES, TOTAL GRAINS, WHOLE GRAINS, MILK & MILK PRODUCTS, MEAT & BEANS, OILS, SATURATED FAT, SODIUM, and CALORIES FROM SOLID FATS, ALCOHOL, & ADDED SUGAR (SoFAAS). To calculate the HEI, an individual's food consumption is first transformed into a base of 1000 calories for diet groups 1–9 and 11. The consumption of each diet group is compared with the recommended level. If the food consumption for a diet group meets the recommended level, it will receive the maximum HEI score for that diet group. Consumption between zero and the recommended quantity are scored proportionately (for more details, see Guenther *et al.* 2007; Patricia *et al.* 2008).

The first six diet groups receive the maximum HEI score of 5, the SoFAAS group receives the maximum score of 20, and the remaining groups receive the maximum score of 10. The total score ranging from 0 to 100 is calculated by summing the scores for all diet groups, which can be used to assess the total diet quality. A higher HEI score indicates better diet quality. Some studies find a negative relationship between HEI and some health problems, implying the effectiveness of using HEI to assess diet quality (Reedy *et al.* 2008).

3. Economic model

On the basis of household production theory (Lancaster 1966; Deaton and Muellbauer 1984), a consumer is assumed to choose marketable goods to produce nonmarketable goods to maximize utility (utility is derived from nonmarketable characteristics rather than from the goods themselves). This is also the case of food consumption for diet. For instance, a sandwich purchased by a consumer may contain ham, tomatoes and leafy greens. The sandwich is what the consumer buys from the market, but the reason that a specific sandwich is chosen may be because the particular items in the sandwich (i.e., ham, tomatoes and leafy greens) contribute to a balanced diet. More generally, assuming $q = (q_1, q_2, \ldots q_n)$ represents marketable foods, by consuming foods q, consumers obtain nutrients from different diet groups. The quality of different diet groups can be represented by $z = (z_1, z_2, \ldots z_g)$, which affects consumer utility levels. The transformation of q into z can be represented by the household production function such that $z = h(q)$. With the assumption that food consumption is weakly separable from other commodity groups, consumer food choices can be modelled through two stages. In the first stage, consumers try to minimize the cost of achieving a certain level of diet quality z, subject to the technology constraint such that

$$\text{Min}C = p \cdot q, \text{subject to } z = h(q). \tag{1}$$

However, with cross-sectional data such as food consumption of 4600 items, food group aggregation is necessary for manageable demand analysis.

Deaton (1987) assumes that there is a constant structure of relative prices within a group and defined group prices. This practice separates quality from price effect in estimating consumer demand for food. However, the constant structure of relative prices is a strong assumption and may not hold in many cases. In this article, we use the unit value of a food group as its price. This price has less problems of endogeneity because the price is calculated from the marketing prices of the 4600 food items. For instance, a consumer may choose two apples and three bananas; the price of the aggregated food (in this case, fruit) can be calculated as the weighted average of the apple and banana prices. Because the prices of apples and bananas are determined by the market, the price of the five pieces of fruit is also exogenous. It should be noted that the price elasticities derived from the cost function may incorporate consumer response to the change in food quality. However, we are more interested in consumer demand for diet quality, which is determined by the prices (shadow prices) of diet groups. To reduce the amount of food items for cost minimization, Equation (1) can be written as

$$\text{Min } C = P \cdot Q = \sum_k P_k Q_k, \text{subject to } z = h(Q), \tag{2}$$

where P_k is the unit value of kth food group, and Q_k is the quantity of *kth* food group.

Solving Equation (2) yields a cost function

$$C = C(P, z), \tag{3}$$

which defines the minimum cost of obtaining a given level of a healthy diet z for any price P. The shadow prices of the diet quality z_i can be calculated as:

$$\pi_i = \partial C/\partial z_i, i = 1, \ldots, 12. \tag{4}$$

Given the shadow prices of the diet groups, the second stage problem for consumers is to

$$\text{Max } u(z) \text{subject to } C^0 = g(\pi, z), \tag{5}$$

where u is a well-defined utility function. The implicit solution of the optimization problem is

$$z_i = z_i(C^0, \pi), \tag{6}$$

which may be considered as consumer demand for the quality of a diet group i. With the shadow price π and expenditure C^0, the demand, as well as the price elasticities of demand for diet quality, can be obtained by estimating the demand system specified in Equation (6).

4. Empirical analysis

4.1. The data

The data on 2-day food consumption and nutrient intakes for 2003–2004 are obtained from the NHANES database, including DIIF and DITN data. DIIF data provide information on the types (corresponding to USDA food codes) and amounts (in grams) of food and beverages consumed by NHANES participants in 2 days. The total calories from DITN are used to transform individual food intake from the absolute amount into intake per 1000 calories. The MyPyramid Equivalents Database (MPED; Bowman *et al.* 2008) is used to transform food intakes into cup or ounce equivalents. In addition, the food products listed in the 2003–2004 CNPP Food Prices Database[4] (FPD) match the ones in DIIF. This enables us to calculate the expenditure on marketable food Q for each participant in the NHANES database (Figure 1).

There are nine major food groups in the USDA FNDDS: Milk and Milk Products; Meat, Poultry and Fish; Eggs; Dry Beans, Legumes, Nuts and Seeds; Grain Products; Fruits; Vegetables; Fats, Oils and Salad Dressings (FOSD); and Sugars, Sweets and Beverages. The nine FNDDS food groups are aggregated into the five marketable USDA food groups: Dairy; Meat, Egg & Beans (MEB); Grains; FV; and Fats, Oils, and Sweets (FS). The food group aggregation corresponds to the diet groups in the analysis. The price of each food group can be calculated as the ratio of expenditure on a certain food group to total gram consumption of that group. Therefore, we obtain the quantity (Q) and price (P) of a given food group that consumers purchase to produce the nonmarketable products (z), which is the HEI measuring diet quality.

4.2. Empirical model

Because no prior information on the cost function is available, a translog cost function is estimated. The translog cost function is one of the most widely used flexible functional forms in empirical analyses (Cowing and Holtmann 1983; Shonkwiler *et al.* 1987). The translog cost function is specified as:

$$\ln C = \alpha_0 + \sum_i^m \alpha_i \ln P_i + \sum_j^m \beta_j \ln z_j + 0.5 \sum_i^n \sum_j^n \alpha_{ij} \ln p_i \ln P_j + 0.5 \sum_i^m \sum_j^m g_{ij} \ln z_i \ln z_j + \sum_i^n \sum_j^m \gamma_{ij} \ln P_i \ln z_j \quad (7)$$

[4] There are 6940 food codes in Food and Nutrient Database for Dietary Studies (FNDDS), representing foods that are usually consumed by U.S. consumers. The CNPP Food Prices Database contains food prices of 4600 foods in an 'as consumed form'. In the 2003–2004 NHANES survey, the number of food items consumed by respondents is 4573. Therefore, the 4600 foods in the CNPP Food Price Database cover most of the foods reported by respondents in the NHANES survey.

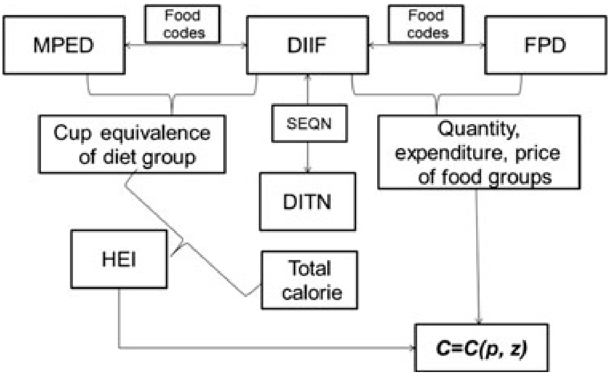

Figure 1 Relationship between data sets used to calculate healthy eating index (HEI), expenditure and price of food.

where C is the individual average expenditure on foods for 2 days; P is the price of marketable foods; z is the HEI measuring the diet quality; $n = 5$ represents the five food groups; and m = 12 represents the 12 diet groups. To avoid the problem of using the log of zero HEI scores, we added one to each HEI.[5]

This shifts the minimum score of each HEI from zero to 1, but is still consistent with the original HEI score. Theoretical restrictions such as homogeneity ($\sum_i^n \alpha_{ij} = 0, \sum_i^n \alpha_i = 1, \sum_i^n \sum_j^m \gamma_{ij} = 0$), and symmetry ($\alpha_{ij} = \alpha_{ji}$, $g_{ij} = g_{ji}$) can be easily imposed on a translog cost function because those restrictions are functions of parameters only. However, in general, concavity on input prices cannot be imposed globally on a translog cost function. If the shares of inputs are not negative, the negative semi-definite property of parameters in matrix A (where A consists of the parameters of $\ln p_i \ln p_j$) is a sufficient condition for global concavity. This approach, however, will lead to the cost function being 'too negative semi-definite', thus resulting in an upwardly biased estimate of cross price elasticities (Diewert and Wales 1987, p. 48). With this concern, we follow Ryan and Wales' approach (2000) to impose concavity at a single observation. In this approach, an observation is chosen as a base point and input prices are then normalized with the prices at the base point. Concavity is imposed by letting

[5] Another way to avoid the problem of zero output levels in estimating translog function is to substitute zero by some arbitrary small number (Cowing and Holtmann 1983) or use a Box-Cox transformation of the original output variables (Caves *et al*. 1980). The first approach was attempted in our analysis, but the arbitrarily chosen small number had great impacts on the final results. The second approach was also attempted, but the estimated lambda coefficients for some HEI index were negative, which also prevented us from transforming the zero HEI scores. Adding one to the original HEI index is the best solution in this case because the HEI index is just an instrument to measure diet quality, not the true nutrient intakes from household production. Adding one to the original HEI index simply scaled the total HEI score from 0–100 to 12–112.

$$\alpha_{ij} = -(UU') + \alpha_i\delta_{ij} - \alpha_i\alpha_j i, j = 1, \ldots, n, \tag{8}$$

where U is a triangular matrix, α_i is the parameter defined in Equation (7) and $\delta_{ij} = 1$ if $i = j$ and 0 otherwise. In the estimation, α_{ij} in Equation (7) is replaced by the right-hand side of equation (8), which will guarantee that concavity is satisfied at the base point.

According to Shephard's Lemma, share equations are derived as:

$$w_i = \frac{p_i q_i}{c} = \frac{\partial \ln C}{\partial \ln p_i} = \alpha_i + \sum_j^n \alpha_{ij} \ln p_j + \sum_j^m \gamma_{ij} \ln z_j, i = 1, \ldots, n. \tag{9}$$

The cost function in Equation (7) and the four share Equations defined by (9) are estimated using the full information maximum likelihood method. The own and cross price elasticity of demand for marketable goods Q_i can be calculated as $\varepsilon_{ii} = \frac{\alpha_{ii}}{w_i} + w_i - 1$, and $\varepsilon_{ij} = \frac{\alpha_{ij}}{w_i} + w_j$, respectively. The shadow price of the diet quality z_j, or HEI, is calculated as

$$\pi_j = \frac{\partial \ln C}{\partial \ln z_j}\frac{c}{z_j} = (\beta_j + \sum_i^m g_{ij} \ln z_i + \sum_i^n \gamma_{ij} \ln p_i) \cdot \frac{c}{z_j}, j = 1, \ldots, m \tag{10}$$

Demand for diet quality in Equation (6) is estimated as a linear function of shadow prices and the quadratic function of food expenditure, together with demographic variables as demand shifters, such as:

$$z_j = \theta_0 + \sum_i^m \theta_i \pi_i + \lambda_1 C + \lambda_2 C^2 + \sum_i^k w_i D_i, j =, \ldots, m \tag{11}$$

where π_i is the shadow price; C is the individual food expenditure; D_i is the demographic variable, such as age and gender. Despite the fact that the shadow prices in (11) may be endogenous, we used ordinary least square (OLS) methods to estimate the system equations of demand for diet quality.[6]

This is a plausible solution due to two facts. First, as pointed out by Deaton and Muellbauer, 'given the two-stage procedure, we can take' Equation (11) 'as behavioural equations, albeit one linking endogenous variables to both exogenous and other endogenous variables'. And 'Sometimes, indeed, the shadow prices are treated like exogenous prices that are independent of the amounts of the nonmarket goods consumed' (Deaton and Muellbauer 1984, p. 248). In addition, even if endogeneity of the shadow price is assumed, OLS methods are still the best choice because very limited information is available to be used as instrumental variables in current cross-

[6] If all explanatory variables are the same for all equations, seemingly unrelated regression estimates are the same as OLS estimates. We also used SUR method to estimate the model; there were no significant difference between those two methods.

section data, and weak instruments may result in worse estimation than OLS methods (Bound *et al.* 1995; Stock *et al.* 2002).

5. Results

5.1. Consumption of foods and the HEI scores

For adult respondents in the NHANES data set, the HEI scores are calculated based on the average food consumption for 2 days. Respondents younger than 20 years old are removed from the analysis because people in this age group may not be the decision maker when it comes to food choices. The number of respondents used in estimating the cost and share equations is 3875, but because of missing demographic information, the number of observations is reduced to 3670 when the demographic variables are added into the demand equation for diet quality. The mean age of the respondents is 51, and the mean Poverty Index Ratio (PIR) is 2.62. The PIR ranges from 0 to 5 and is the ratio of income to the household poverty threshold based on household size which also contains information on household income. Other respondent demographics are reported in Table 1.

The average daily food expenditure is about \$4.32, ranging from \$0.39 to \$18.35. Among the five USDA food groups, MEB expenditure is the highest at \$2.92/kg, and Dairy expenditure is the lowest at \$0.47. In case of quantity consumed, the FS consumption is the highest, about 1.9 kg/day (Figure 2).

The average total HEI score is 56.21. The SoFAAS diet group receives the highest score of 10.46 and the WHOLE GRAINS diet group receives the lowest score of 1.17 (Table 2). However, because the maximum HEI scores of different diet groups are different, the relative score calculated as the ratio between the HEI score and the maximum score of a corresponding diet group provides more useful information. The ratio between the mean HEI score and the maximum score for WHOLE GRAINS is the lowest, about 0.23, which implies that the average consumption of whole grain is only 23 per cent of the recommended level of the 2005 DGA. The ratios of both TOTAL GRAINS and MEB are about 0.89, indicating optimal consumption of food containing total grains, meat and beans. The ratios of 0.39 for SODIUM and 0.29 for DARK GREEN & ORANGE VEGETABLES & LEGUMES indicate overconsumption of sodium and under-consumption of food containing dark green and orange vegetables as well as legume.

5.2. Estimates of cost and share equations

The cost and share equations are estimated with homogeneity, symmetry and concavity conditions imposed. To impose concavity, the cost and share equations are first estimated with each observation as the base point. After each estimation, the concavity conditions are checked for all the observations

Table 1 Respondent demographics

Demographic variable	Statistics
Age	51.03[a](19.55)[b]
PIR	2.61 (1.59)
Gender	
Male	47.10%
Marital status	
Marriage1: Married	55.47%
Marriage2: Widowed	11.23%
Marriage3: Divorced	9.37%
Marriage4: Separated	2.56%
Marriage5: Never Married	15.2%
Marriage6: Living with Partner	6.17%
Education	
Edu1: Less than 9th Grade	13.83%
Edu2: 9–11 Grade	14.55%
Edu3: High School Grade/GED or Equivalent	24.46%
Edu4: Some College or AA Degree	27.69%
Edu5: College Graduate or Above	19.46%
Ethnicity	
Eth1: Non-Hispanic White	56.03%
Eth2: Non-Hispanic Black	17.63%
Eth3: Mexican American	20.52%
Eth4: Other Race, Including Multi-Racial	2.81%
Eth5: Other Hispanic	3.02%

Notes: PIR, poverty index ratio. [a]Means of variables in sample. [b]Numbers in parentheses are standard deviations.

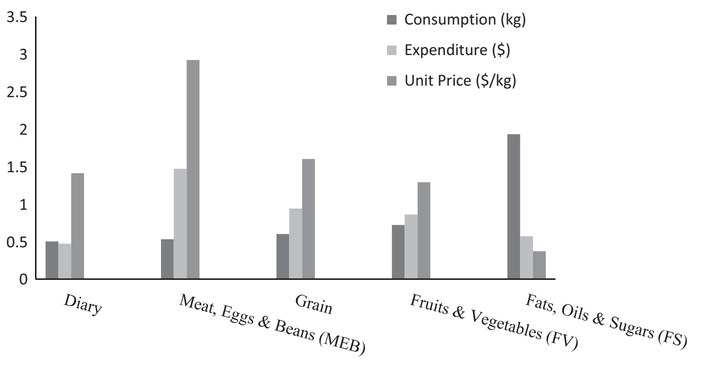

Figure 2 Food consumption, expenditure and price.

and the final model is selected with which the concavity conditions are satisfied at the most observations. In the final model, the concavity condition is satisfied at about 71 percentage of the total observations.

For the translog cost function and the share equations, the estimates of the parameters of food prices ($\alpha_{i,}$) are all significant at the 5 per cent significance level, and most parameters of the interactions of food prices and HEIs (γ_{ij})

Table 2 The HEI score of total and individual diet group

Variable	Description	Mean	Std. dev	HEI/HEI Max
HEI	TOTAL HEI-2005 SCORE	56.21	13.31	0.56
HEI1	TOTAL FRUIT	2.67	1.96	0.53
HEI2	WHOLE FRUIT	2.57	2.15	0.51
HEI3	TOTAL VEGETABLES	3.34	1.42	0.67
HEI4	DARK GREEN & ORANGE VEGETABLES & LEGUMES	1.47	1.70	0.29
HEI5	TOTAL GRAINS	4.45	0.89	0.89
HEI6	WHOLE GRAINS	1.17	1.42	0.23
HEI7	MILK & MILK PRODUCTS	5.33	3.05	0.53
HEI8	MEAT & BEANS	8.88	1.93	0.89
HEI9	OILS	6.07	3.12	0.61
HEI10	SATURATED FAT	5.86	3.31	0.59
HEI11	SODIUM	3.94	2.82	0.39
HEI12	CALORIES FROM SOLID FAT, ALCOHOL & ADDED SUGAR (SoFAAS)	10.46	5.96	0.52

Note: HEI, healthy eating index.

are statistically significant.[7] The significance of γ_{ij} implies that diet quality affects the budget shares of different food groups. More than half of γ_{ij} are negative, implying that increasing the HEI score (diet quality) of certain diet groups will reduce the spending on some food groups.

The price elasticities of demand for food groups shown in Table 3 are the means of the elasticities calculated at each observation. Most of the own-price elasticities are statistically significant, negative and less than unity, with Dairy having the largest own-price elasticity in terms of absolute values. All the cross price elasticities, except for the elasticity between FV and Grain, are positive, implying that most of the food groups are substitutes.

5.3. Demands for a healthy diet

For each observation, shadow prices and their variances are calculated. The mean shadow prices of all 12 diet groups are significant at the 5 per cent significance level. The proportions of significant shadow prices for individual diet group differ markedly (Table 4). The mean shadow price of HEI4 (DARK GREEN & ORANGE VEGETABLES & LEGUMES) is the highest at \$0.63, followed by HWI7 (MILK & MILK PRODUCTS, 0.47) and HEI1 (TOTAL FRUIT, 0.45). The negative shadow prices of some HEIs may be the result of not imposing monotonicity on the cost function. However, not imposing monotonicity is a reasonable choice because increasing nutrient intake does not necessarily improve the diet quality and may even impair diet quality (e.g., SATURATED FAT). The negative shadow prices of HEI5 (TOTAL GRAINS), HEI8 (MEAT & BEANS) and

[7] Due to the page limit, the estimates of parameters of cost and share equations are not reported, but are available per the request of readers.

Table 3 Estimates of own and cross price elasticity of demand for foods

	Compensated price elasticities				
	ε_{i1}	ε_{i2}	ε_{i3}	ε_{i4}	ε_{i5}
Dairy	−0.66*	0.18*	0.08*	0.18*	0.22*
Meat, Egg and Beans (MEB)	0.16*	−0.39*	0.02	0.14*	0.07
Grain	0.17*	0.09*	−0.42*	0.03	0.13*
Fruits and Vegetables (FV)	0.08*	0.10*	−0.08*	−0.17	0.06*
Fats, Oils and Sweets (FS)	0.40*	0.06*	0.05*	0.11*	−0.62*

Notes: *Indicates statistically significant at 5% significance level.

Table 4 Shadow price of HEI

Variable	Description	Means	Portion of shadow prices that are statistically significant	
HEI1	TOTAL FRUIT	0.45a	29%b	41%c
HEI2	WHOLE FRUIT	0.35	92%	93%
HEI3	TOTAL VEGETABLES	0.13	42%	50%
HEI4	DARK GREEN & ORANGE VEGETABLES & LEGUMES	0.63	79%	83%
HEI5	TOTAL GRAINS	−0.32	71%	78%
HEI6	WHOLE GRAINS	0.29	63%	69%
HEI7	MILK & MILK PRODUCTS	0.47	99%	99%
HEI8	MEAT & BEANS	−0.02	6%	13%
HEI9	OILS	0.02	39%	48%
HEI10	SATURATED FAT	−0.02	5%	10%
HEI11	SODIUM	0.19	33%	38%
HEI12	CALORIES FROM SOLID FAT, ALCOHOL & ADDED SUGAR (SoFAAS)	0.05	34%	44%

Notes: HEI, healthy eating index. [a]Mean shadow price of all respondents. [b]Percentage of shadow prices that are statistically significant at 5% significance level.[c]Percentage of shadow prices that are statistically significant at 10% significance level.

HEI12 (SATURATED FAT) imply that in general consumers can improve their diet quality of those groups without increasing food expenditures.

The estimates of a system of demand equations for diet quality are reported in Table 5. In the estimation, dummy variables are created for categorical demographic variables in Table 1. The dummy variable of the last category of each demographic variable is removed. The results show that overall the shadow prices of HEI significantly affect consumer demand for diet quality. Increasing food expenditure significantly improves the diet quality of TOTAL FRUIT (HEI1); WHOLE FRUIT (HEI2); DARK GREEN & ORANGE VEGETABLES & LEGUMES (HEI4); MILK & MILK PRODUCTS (HEI7); OILS (HEI9); and SODIUM (HEI11) while at the same time

Table 5 Estimate of demand for diet quality

	HEI1	HEI2	HEI3	HEI4	HEI5	HEI6	HEI7	HEI8	HEI9	HEI10	HEI11	HEI12
Constant	4.394*	3.874*	4.797*	3.105*	5.630*	2.574*	4.986*	10.570*	7.150*	10.047*	4.528*	18.352*
$\pi 1$[a]	−2.583*	−1.375*	0.481*	0.146*	0.012	0.008	0.301*	−0.245*	0.132	0.045	−0.210*	−1.972*
$\pi 2$	−0.572*	−1.388*	−0.113*	−0.085*	−0.046*	−0.231*	0.047	−0.157*	−0.102*	−0.374*	−0.098*	−1.313*
$\pi 3$	−0.068	−0.120	−3.649*	−1.130*	0.387*	−0.225*	−0.057	−0.502*	−0.468*	1.960*	0.918*	−3.035*
$\pi 4$	−0.192*	−0.043	−0.662*	−1.579*	0.003	−0.160*	0.495*	−0.444*	−0.316*	−0.044	0.242*	−1.629*
$\pi 5$	−0.194*	−0.129	0.224*	−0.099	−1.811*	−1.022*	−1.595*	−0.472*	0.459*	3.634*	0.535*	−3.961*
$\pi 6$	0.132*	0.088*	−0.042	−0.010	−0.294*	−1.777*	0.147	0.195*	0.001	−0.597*	−0.022	−0.694*
$\pi 7$	0.397*	0.183*	0.053	0.281*	−0.368*	−0.414*	−5.550*	0.011	0.720*	1.781*	1.256*	−3.934*
$\pi 8$	−1.373*	−1.301*	−0.984*	−1.035*	0.152	−1.023*	−3.248*	−10.182*	−2.384*	0.791	0.414	−10.972*
$\pi 9$	0.410*	0.423*	−0.035	0.108	0.123	0.004	1.977*	−1.020*	−10.811*	2.102*	0.497*	−2.926*
$\pi 10$	−0.157	−1.047*	1.069*	−0.281	1.497*	−0.373*	0.113	−2.092*	1.869*	3.313*	−1.129*	−3.839*
$\pi 11$	−0.324*	−0.085	0.479*	0.221*	0.176*	0.387*	1.107*	−0.281*	−0.492*	−1.348*	−5.553*	1.551*
$\pi 12$	1.228*	0.977*	−0.593*	0.592*	−1.214*	−0.494*	4.417*	−0.624*	−2.348*	−5.86*	2.174*	−7.017*
C	0.104*	0.100*	0.017	0.059*	−0.081*	−0.047*	0.500*	−0.113*	0.090*	−0.193*	0.219*	−0.405*
C^2	−0.004*	−0.004*	−0.002*	−0.002	0.002*	0.001	−0.011*	0.002	−0.005*	0.004	−0.006*	0.012*
Age[b]	0.008*	0.010*	0.008*	0.007*	−0.001	0.008*	0.001	−0.001	0.008*	−0.004	−0.001	0.028*
Male	−0.349*	−0.265*	−0.185*	−0.216*	0.026	−0.060	−0.760*	0.441*	−0.274*	0.107	−0.180*	−0.549*
Eth1	−0.178	−0.090	−0.09	−0.157	0.028	0.063	0.427	−0.492*	0.383	−1.366*	−0.452*	−1.899*
Eth2	−0.185	−0.255*	−0.165	−0.036	−0.231*	−0.043	−0.278	−0.079	0.384	−1.126*	−0.216	−2.373*
Eth3	0.020	0.090	0.055	0.071	0.084	0.022	0.156	−0.341*	−0.213	−0.647*	−0.060	−1.110*
Eth4	−0.077	−0.156	0.177	−0.164	−0.064	0.124	−0.393	−0.171	0.455	0.447	−0.588*	0.500

Table 5 (*Continued*)

	HEI1	HEI2	HEI3	HEI4	HEI5	HEI6	HEI7	HEI8	HEI9	HEI10	HEI11	HEI12
Marriage1	0.092	0.099	0.041	−0.007	0.018	−0.004	0.122	0.087	−0.235	0.131	0.147	0.122
Marriage2	0.113	0.208	−0.018	0.033	−0.05	−0.023	0.365	0.034	−0.755*	0.055	0.168	−0.142
Marriage3	0.000	0.012	−0.089	−0.162	−0.034	0.040	0.210	0.131	−0.333	0.130	−0.028	0.095
Marriage4	0.145	0.160	−0.122	−0.163	−0.096	0.005	0.647*	−0.358*	−0.476	0.596	0.198	−0.235
Marriage5	0.202*	0.164	0.073	0.153	−0.087	0.124	0.306	−0.036	−0.035	0.294	0.356*	0.346
PIR	−0.004	−0.014	0.023	−0.004	−0.011	0.009	−0.007	0.042*	0.003	0.057	−0.038	0.036
Edu1	−0.322*	−0.349*	−0.145*	−0.259*	0.023	−0.175*	−0.074	0.217*	−0.501*	−0.010	0.208	−1.094*
Edu2	−0.306*	−0.276*	−0.129*	−0.318*	−0.002	−0.180*	−0.238	0.248*	−0.462*	−0.542*	0.099	−1.973*
Edu3	−0.257*	−0.194*	−0.182*	−0.329*	−0.027	−0.153*	−0.179	0.194*	−0.129	−0.664*	0.120	−1.719*
Edu4	−0.175*	−0.162*	−0.139*	−0.164*	−0.028	−0.094	−0.093	0.165*	−0.124	−0.515*	0.105	−1.642*
Adjusted R^2	0.659	0.716	0.562	0.606	0.452	0.511	0.454	0.439	0.432	0.311	0.502	0.364
N						3670						

Notes: Three decimal places are used because many estimates will be zero if two decimal places are used. HEI, healthy eating index; PIR, poverty index ratio. *Indicates statistically significant at 5% significance level. [a]Shadow price of HEIj, j = 1–12. [b]Demographic variables are corresponding to those in Table 1.

decreasing the diet quality of other diet groups. The quadratic relationship between food expenditure and diet quality may exist; however, although significant, all the estimates for expenditure squares are close to zero.

Age, though small in scale, significantly and positively affects consumer demand for quality of most diet groups, which indicates that older people care more about the healthy impacts of food consumption. The demand for quality of most diet groups of men is significantly less than that of women, with the exception of MEAT & BEANS (HEI8). This indicates that males are more likely to obtain energy from the consumption of meat and beans (most likely meats) than from other food products. Ethnicity and marital status in general do not significantly affect consumer demand for diet quality.

The coefficients of PIR in all equations except for the equation of HEI8 are not statistically significant. This indicates that income in general does not significantly affect consumer demand for diet quality. However, education has significant impacts on the demand for diet quality: consumers with less advanced degrees demand less for the diet quality of most diet groups except for the diet quality of MEAT & BEANS (HEI8).

Most of the elasticities of demand for diet quality are statistically significant at the 5 per cent significance level (Table 6). HEI4 (DARK GREEN & ORANGE VEGETABLES & LEGUMES) has the largest own-price elasticity, followed by HEI11 (SODIUM), HEI1 (TOTAL FRUIT) and HEI2 (WHOLE FRUIT). The cross price elasticities between HEI12 (SoFAAS) and most HEIs are close to zero, indicating that a change in the shadow price of the quality of SoFAAS does not have large impacts on the quality of other diet groups. Among the 12 expenditure elasticities, five of them are negative. This implies that with more expenditures on foods, the demand for the qualities of diet groups such as TOTAL VEGETABLES (HEI3), WHOLE GRAINS (HEI6) and MEAT & BEANS (HEI8) decrease.

5.4. Impact of taxes on diet quality

For each individual in the data, the diet quality after a tax change on selected foods is calculated and compared with the diet quality before the tax. Because all the foods are included when estimating the cost (Equation 7) and share (Equation 9) equations, it is very flexible to simulate the impacts of tax changes of any foods or food groups on diet quality. This is different from previous studies that only focus on a subset of food and conduct the analysis under the assumption of weak severability of a food group (Duffey *et al.* 2010; Lin *et al.* 2011). Following Lin *et al.* we simulate the impact of excise taxes such that consumers will face a 20 percentage price increase on selected foods in the market. In addition to the 20 percentage tax on sugar-sweetened beverage (SWB) in Lin *et al.*, we also simulate the impact of a 20 per cent tax on FOSD because of the recent introduction of a ‘fat tax’ in countries such as Denmark (Mytton *et al.* 2012). The focus is whether the 20 per cent taxes impact consumer diet quality, and if they do, which tax is more effective.

Table 6 Price and expenditure elasticity of demand for diet quality

Diet quality	Uncompensated price elasticities												Expenditure elasticities
	ε_{i1}	ε_{i2}	ε_{i3}	ε_{i4}	ε_{i5}	ε_{i6}	ε_{i7}	ε_{i8}	ε_{i9}	ε_{i10}	ε_{i11}	ε_{i12}	
HEI1	−0.788a	−0.179	−0.004	−0.053	0.025	0.018	0.080	0.011	0.000[b]	0.003	−0.026	0.026	0.114
HEI2	−0.392	−0.707	−0.007	−0.014	0.020	0.012	0.042	0.015	0.002	0.021	−0.007	0.023	0.115
HEI3	0.055	−0.013	−0.218	−0.122	−0.020	−0.003	0.007	0.004	0.000	−0.008	0.022	−0.008	−0.015
HEI4	0.038	−0.024	−0.069	−0.999	0.020	−0.002	0.082	0.009	0.001	0.004	0.024	0.020	0.120
HEI5	0.001	−0.003	0.008	0.000	0.096	−0.016	−0.034	−0.001	0.000	−0.009	0.006	−0.013	−0.064
HEI6	0.003	−0.062	−0.017	−0.068	0.224	−0.577	−0.131	0.007	0.000	0.005	0.048	−0.013	−0.106
HEI7	0.030	0.003	−0.002	0.061	0.115	0.010	−0.704	0.002[c]	0.005	0.000	0.036	0.044	0.416
HEI8	−0.012	−0.006	−0.007	−0.032	0.017	0.006	0.001	−0.023	−0.003	0.002	−0.005	−0.003	−0.058
HEI9	0.010	−0.007	−0.012	−0.038	−0.028	0.000	0.063	0.005	−0.306	−0.010	−0.017	−0.022	0.024
HEI10	0.006	−0.053	0.031	−0.009	−0.378	−0.059	0.220	−0.004	−0.002[d]	−0.055	−0.090	−0.102	−0.207
HEI11	−0.034	−0.012	0.040	0.049	−0.060	−0.003	0.193	−0.004	0.003	0.008	−0.849	0.026	0.273
HEI12	−0.206	−0.152	−0.073	−0.237	0.161	−0.020	−0.384	−0.030	−0.014	0.029	0.033	−0.113	−0.228

Notes: HEI, healthy eating index. Three decimal places are used because many estimates will be zero if two decimal places are used. All elasticities are statistically significant at 5% significance level, except for b, c and d. [a]Mean of elasticities calculated for all individuals in the sample.

Results show that although the magnitudes of the changes in the quality of all diet groups are small, SWB and FOSD taxes both significantly affect the diet quality. Overall, the SWB tax has a larger impact on the improvement of the diet quality. The average total HEI changed from 56.21 to 56.30 with a SWB tax and to 56.24 with a FOSD tax.

6. Conclusion

Although there are many studies on consumer demand for foods, studies on demand for diet quality are limited. In this article, we systematically study consumer demand and the factors affecting demand for diet quality. We also simulate the impacts of two exercise taxes on diet quality. The framework used in this article can be adapted in similar studies in other countries. The studies on consumer demand for diet quality are important because in many cases policy instruments such as taxes and subsidies are implemented on diet groups rather than on food products. For instance, to discourage consumers' fat intake from meats, it is clumsy to have a tax on hamburger but it is possible to have a tax on 'meat'. The term 'meat' is actually more consistent with diet group because it consists of many different types of meats. In addition, governments may encourage food producers to label the diet quality (e.g., HEI score) of food products to help consumers easily make choices of healthy food. One example is the Guiding Stars system introduced by some retailers in which a system of zero to three stars is used to indicate the nutrition value of the food sold (Farwell 2011).

Similar to the conclusions of another study (Krebs-Smith *et al.* 1995), our results show that U.S. consumer consumption of some foods such as dark green and orange vegetables and whole grain is inadequate. The lack of consumption of these foods may be the result of the high shadow prices of the diet quality of the diet groups. Although the average price of meat and beans is high, consumers get enough meat and beans in their diet because of the low shadow price for the diet quality of MEAT & BEANS.

Our results show that income in general does not have a significant impact on consumer demand for diet quality, which is different from the results of Mancino *et al.* (2004) and Darmon and Drewnowski (2008). Possible reasons may be that Mancino *et al.* use the total HEI score, and Darmon and Drewnowski use dietary energy density as the index of overall diet quality. Our study uses the HEIs of the 12 diet groups and controls the price effect of diet quality. However, our results are consistent with some previous findings that income does not have significant impacts on the consumption of some food groups and diet quality (Wilde *et al.* 1999; Stewart *et al.* 2003). In addition, our results show that education has significant impacts on consumer diet selection which indicates that people with higher education levels may have better access to and understanding of the sometimes complicated information on the health benefits of foods. This reflects the importance of some of the nutritional education campaigns that aim to help consumers be aware of and understand the healthy benefits of foods (Kelder *et al*. 1995; Perez-Escamilla *et al*. 2008). Increasing social pressure by delivering educational messages and information to less educated people may be the right public health effort to increase consumers' healthy food choices. At last, the results from the simulations of the SWB and FOSD taxes show that taxes can be used as effective instruments to improved diet quality, and SWB tax may be more effective than FOSD tax.

The results of this study may provide critical and valuable information for policy makers and stakeholders that are targeting the improvement of diet quality. It can be further extended to study the linkage between the demand for diet quality and individual health problems such as obesity. The lack of regional food price information prevents us from investigating consumer demand for diet quality across regions. With regional data available, regional demand for diet quality can be estimated and more customized public health policies and programs can be designed for a specific region. In addition, the impacts of the SWB and FOSD taxes on individual health conditions warrant further research under the current framework because the changes in diet quality as a result of imposing a food tax are small, although significant.

References

Bound, J., Jaeger, D.A. and Baker, R.M. (1995). *Problems with instrumental variables estimation when the correlation between the instruments and the endogenous explanatory variables is weak*, *Journal of American Statistical Association* 90, 443–450.

Bowman, S.A., Friday, J.E. and Moshfegh, A.J. (2008). MyPyramid Equivalents Database, 2.0 for USDA Survey Foods, 2003–2004. Agricultural Research Service, United States Department of Agriculture, Washington, DC. Available from URL: http://www.ars.usda.gov/ba/bhnrc/fsrg [accessed 6 June 2011].

Brown, M.G., Behrm, R.M. and Lee, J.-Y. (1994). *Conditional demand and endogeneity? A case study of demand for juice products*, *Journal of Agricultural and Resource Economics* 19, 129–140.

Cade, J., Upmeier, H., Calvert, C. and Greenwood, D. (1999). *Costs of a healthy diet: analysis from the UK women's cohort study*, *Public Health Nutrition* 2, 505–512.

Caves, D.W., Christensen, L.R. and Swanson, J.A. (1980). *Productivity in US railroads, 1951–1974*, *The Bell Journal of Economics* 11, 166–181.

CDC (2007). National Health and Nutrition Examination Survey. Center for Disease Control and Prevention, Atlanta, GA.

Cowing, T.G. and Holtmann, A.G. (1983). *Multiproduct short-run hospital cost functions: empirical evidence and policy implications from cross-section data*, *Southern Economic Journal* 49, 637–653.

Darmon, N. and Drewnowski, A. (2008). Does social class predict diet quality?, *The American Journal of Clinical Nutrition* 87, 1107–1117.

Deaton, A. (1987). *Estimation of own- and cross-price elasticities from household survey data*, *Journal of Econometrics* 36, 7–30.

Deaton, A. and Muellbauer, J. (1984). Economics and Consumer Behavior. Cambridge University Press, New York.

Diewert, W.E. and Wales, T.J. (1987). *Flexible functional forms and global curvature conditions*, *Econometrica* 55, 43–68.

Drewnowski, A. and Darmon, N. (2005). *Food choices and diet costs: an economic analysis*, *Journal of Nutrition* 135, 900–904.

Duffey, K.J., Gordon-Larsen, P., Shikany, J.M., Guilkey, D., Jacobs, D.R. Jr and Popkin, B.M. (2010). *Food price and diet and health outcomes: 20 years of the Cardia study*, *Archives of Internal Medicine* 170, 420–426.

Eastwood, M.A., Brydon, W.G., Baird, J.D., Elton, R.A., Helliwell, S., Smith, J.H. and Pritchard, J.L. (1984). *Fecal weight and composition, serum lipids, and diet among subjects aged 18 to 80 years not seeking health care*, *American Journal of Clinical Nutrition* 40, 628–634.

Farwell, J. (2011). Guiding Stars Nutritional Ratings Implemented in Hospital Cafeterias. Bangor Daily News, Bangor, ME, USA. Available from URL: http://bangordailynews.com/2011/12/08/health/guiding-stars-nutritional-ratings-implemented-in-hospital-cafeterias/ [accessed 3 March 2012].

Guenther, P.M., Reedy, J., Krebs-Smith, S.M., Reeve, B.B. and Basiotis, P.P. (2007). Development and Evaluation of the Healthy Eating Index 2005: Technical Report. Center for Nutrition Policy and Promotion, United States Department of Agriculture, Washington, DC.

Guenther, P.M., Krebs-Smith, S.M., Reedy, J., Britten, P., Juan, W., Lino, M., Carlson, A., Hiza, H.A. and Basiotis, P.P. (2008). Healthy Eating Index 2005, CNPP Fact Sheet No.1. USDA Center for Nutrition Policy and Promotion and National Cancer Institute, Alexandria, VA, USA.

Heien, D. and Pompelli, G. (1989). *The demand for alcoholic beverages: economic and demographic effects*, *Southern Economic Journal* 55, 759–770.

Kelder, S.H., Perry, C.L., Lytle, L.A. and Klepp, K.I. (1995). *Community-wide youth nutrition education: long-term outcomes of the Minnesota Heart Health Program*, *Health Education Research* 10, 119–131.

Krebs-Smith, S.M., Cook, A., Subar, A.F., Cleveland, L. and Friday, J. (1995). *US adults' fruit and vegetable intakes, 1989 to 1991: a revised baseline for the healthy people 2000 objective*, *American Journal of Public Health* 85, 1623–1629.

Lancaster, K.J. (1966). *A new approach to consumer theory*, *The Journal of Political Economy* 75(2), 132–157.

Lee, J.-Y. (1987). *The demand for varied diet with econometric models for count data*, *American Journal of Agricultural Economics* 69, 687–692.

Lin, B.H., Smith, T.A., Lee, J.Y. and Hall, K.D. (2011). *Measuring weight outcomes for obesity intervention strategies: the case of a sugar-sweetened beverage tax*, *Economics & Human Biology* 9, 329–341.

Lo, Y.T., Chang, Y.H., Lee, M.S. and Wahlqvist, M.L. (2009). *Health and nutrition economics: diet costs are associated with diet quality*, *Asia Pacific Journal of Clinical Nutrition* 18, 598–604.

Mancino, L, Lin, B. and Ballenger, N. (2004). The Role of Economics in Eating Choices and Weight Outcomes, *Agriculture Information Bulletin, Bulletin No. (AIB-791)*, Washington, DC.

Mytton, O., Clarke, D. and Rayner, M. (2012). *Taxing unhealthy food and drinks to improve health*, *BMJ* 344, 2931.

O'Neil, C.E., Keast, D.R., Fulgoni, V.L. III and Nicklas, T.A. (2010). *Tree nut consumption improves nutrient intake and diet quality in US adults: an analysis of National Health and Nutrition Examination Survey (NHANES) 1999–2004*, *Asia Pacific Journal of Clinical Nutrition* 19, 142–150.

Patricia, M.G., Jill, R. and Susan, M.K.-S. (2008). *Development of the healthy eating index 2005*, *Journal of the American Dietetic Association* 108, 1896–1901.

Perez-Escamilla, R., Hromi-Fiedler, A., Vega-Lopez, S., Bermudez-Millan, A. and Segura-Perez, S. (2008). *Impact of peer nutrition education on dietary behaviors and health outcomes*

among Latinos: a systematic literature review, *Journal of Nutrition Education and Behavior* 40, 208–225.
Reedy, J., Mitrou, P.N., Krebs-Smith, S.M., Wirfalt, E., Flood, A., Kipnis, V., Leitzmann, M., Mouw, T., Hollenbeck, A., Schatzkin, A. and Subar, A.F. (2008). *Index-based dietary patterns and risk of colorectal cancer: the NIH-AARP diet and health study*, *American Journal of Epidemiology* 168, 38–48.
Ryan, D.L. and Wales, T.J. (2000). *Imposing local concavity in the translog and generalized Leontief cost functions*, *Economics Letters* 67, 253–260.
Schmidt, M., Affenito, S.G., Striegel-Moore, R., Khoury, P.R., Barton, B., Crawford, P., Kronsberg, S., Schreiber, G., Obarzanek, E. and Daniels, S. (2005). *Fast-food intake and diet quality in black and white girls: the National Heart, Lung, and Blood Institute growth and health study*, *Archives of Pediatrics & Adolescent Medicine* 159, 626–631.
Shonkwiler, J.S., Lee, J. and Taylor, T.G. (1987). *An empirical model of the demand for a varied diet*, *Applied Economics* 19, 1403–1410.
Stewart, H., Blisard, N. and Jolliffe, D. (2003). *Do income constraints inhibit spending on fruits and vegetables among low-income households?*, *Journal of Agricultural and Resource Economics* 28, 465–480.
Stock, J.H., Wright, J.H. and Yogo, M. (2002). *A survey of weak instruments and weak identification in generalized method of moments*, *Journal of Business & Economic Statistics* 20, 518–529.
Thiele, S. and Weiss, C. (2003). *Consumer demand for food diversity: evidence for Germany*, *Food Policy* 28, 99–115.
USDA-CNPP (2009). CNPP Food Prices Database, 2003–2004. Center for Nutrition Policy and Promotion, United States Department of Agriculture, Washington, DC. Available from URL: http://www.cnpp.usda.gov/usdafoodplanscostoffood.htm [accessed 6 June 2011].
Vining, E.P. (2008). *Long-term health consequences of epilepsy diet treatments*, *Epilepsia* 49 (Suppl 8), 27–29.
Wilde, P.E., McNamara, P.E. and Ranney, C.K. (1999). *The effect of income and food programs on dietary quality: a seemingly unrelated regression analysis with error components*, *American Journal of Agricultural Economics* 81, 959–971.